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Rising tide of energy nationalism

THIS issue of *Nature* is devoted largely to energy questions as seen by the scientist, from the whisky distillery in Scotland to the cattle dung plants of agricultural India. We cannot claim to be comprehensive in our coverage, but since it is not entirely unfashionable these days to devote large portions of journals to energy considerations it is unlikely that by half way through 1974 anyone who reads at all could claim that he lacked adequate briefing on almost any aspect of the energy situation. And yet it may be that although one can emerge convinced that there are large numbers of competent people in many countries exploring every avenue and leaving no stone unturned, there is still something naggingly wrong with the utterances of policy makers. "Self sufficiency by the 1980s", "indigenous resources", "national energy research strategies". Is not this talk the distant rumblings of a nationalism in science and technology that could make energy as isolated a field to work in as defence?

For some time, of course, marketing of energy has fostered nationalism through the possibilities of economic warfare, and the events of last winter must presumably be called an energy skirmish if nothing else. It is inevitable that countries which have traditionally disliked each other will now use energy as a weapon with no more hesitation than they have used blockades in the past. That is hardly a matter for debate. What is debatable is whether the remarkable nationalism that the energy crisis has engendered even amongst allies can do anything but harm to world order, and lead to tensions where previously there were none, and unnecessary duplication of activity where previously there was collaboration.

The disturbing thing for a scientist is not just that the possession of energy should be viewed in a national framework but that research itself into all aspects of energy should also be seen as too exclusively a national property. For instance, is it rational to talk of a programme to make the United States independent of the external world in energy matters when it shares thousands of miles of frontier, one common language and many similarities in life-style with Canada? Is the great nuclear reactor debate in Britain one which is too polarised into Britain against the United States. Is it further, one which should have been conducted at an international, or at least, a European level? If brain power as well as energy were regarded as a valuable resource the answer to all these questions would be yes. The giant oil companies have been an interesting example of supranational research and development; it would be unfortunate if with the decline in their influence this

mode of operation were to be lost entirely, when it could with profit be used as a model for others.

If narrow interests restricted by geographical frontiers are to be overcome it is urgently necessary that international initiatives be pursued with great vigour. For this reason a proposal of Lord Robens on page 699 is worthy of attention. He suggests the formation of international energy research projects for such matters of common interest as solar energy. It is only around fairly specific objects that international research collaboration is likely to gel, and this as much as anything may be the reason the scientific community has been almost silent on the Kissinger initiative to internationalise energy concerns.

Solar energy would be an ideal project if only because of its world-wide applicability. As Dr Brinkworth points out on page 729, research and development in solar energy could also be seen as a means of giving aid to developing countries. What is more, the equipment need not be so complex that it is impossible to build and operate except in high technology societies. This too is a subtle consequence of too much national research policy; that the device only works when its maker is on hand and consequently it proves impossible to export. Further, if the work is removed to a government laboratory the economic need for an exportable product may be less to the fore and the formal obstacles to international collaboration much more extensive.

The dangers of nationalism in energy research are great. The antidote to them is not to be found in international committees of bureaucrats but in grass roots action by scientists themselves working across frontiers.

100 years ago



Proposed Issue of Daily Weather Charts of Europe and the North Atlantic

I HAVE the honour to inform you that Capt. Hoffmeyer, Director of the Royal Meteorological Institute of Copenhagen, has sent me a circular announcing his intention to publish daily charts of the weather for the district from 60° E. to 60° W. long. and from 30° to 75° N. lat. The charts for the three months—Dec. 1873-Feb. 1874—will be published as an experiment.

The cost will be four francs per month, exclusive of postal charges.

Capt. Hoffmeyer states that he can only deal with central offices, and has requested me to undertake these islands as regards the distribution of the charts. I have therefore to announce that I have been instructed by the committee to subscribe for twenty-five copies of these charts, and I shall be happy to supply copies for the three months to any gentleman, at the cost of 11s. to cover carriage from Copenhagen, and postage from London to his address.

ROBERT H. SCOTT, *Director*
Meteorological Office, June 22

From *Nature*, 10, 146, June 25, 1875.



Sealing wax and string at \$250 million

Miranda Robertson discusses the contribution that the Fermi National Accelerator Laboratory (pictured at bottom) is making to high energy physics.

THE dedication last month of the National Accelerator Laboratory (FNAL) to Enrico Fermi was a tribute to the man and an acknowledgment of the traditional link between the Chicago laboratory which saw the first nuclear chain reaction and the laboratory at Batavia, 35 miles west of Chicago, which now houses Fermi's original Chicago cyclotron (demoted to muon focussing) as well as the world's most powerful proton accelerator.

But historical links apart, the laboratory must stand as a monument to its director Robert Wilson, one of many ex-colleagues or students of Fermi now working at Batavia. When he agreed in 1967 to undertake the task of constructing the machine, Wilson brought to an already controversial project not only the experience he had gained in building the Cornell accelerator, but his own controversial approach—a latter-day, \$250-million version of the sealing-wax-and-string tradition combined with a willingness to take a venture on the chance of greater dividends.



Robert Wilson: controversial

The commitment of funds to so expensive a project was a problem from the start. Wilson's achievement has been to do more than was planned with less than was hoped: to build a 500-GeV accelerator instead of a 200-GeV one with an initial commitment of \$250 million instead of \$350 million. A second source of early contention was the siting in America's middle West of what was to be an important international research centre. The geodesic dome of the bubble-chamber assembly building, the curved and cor-

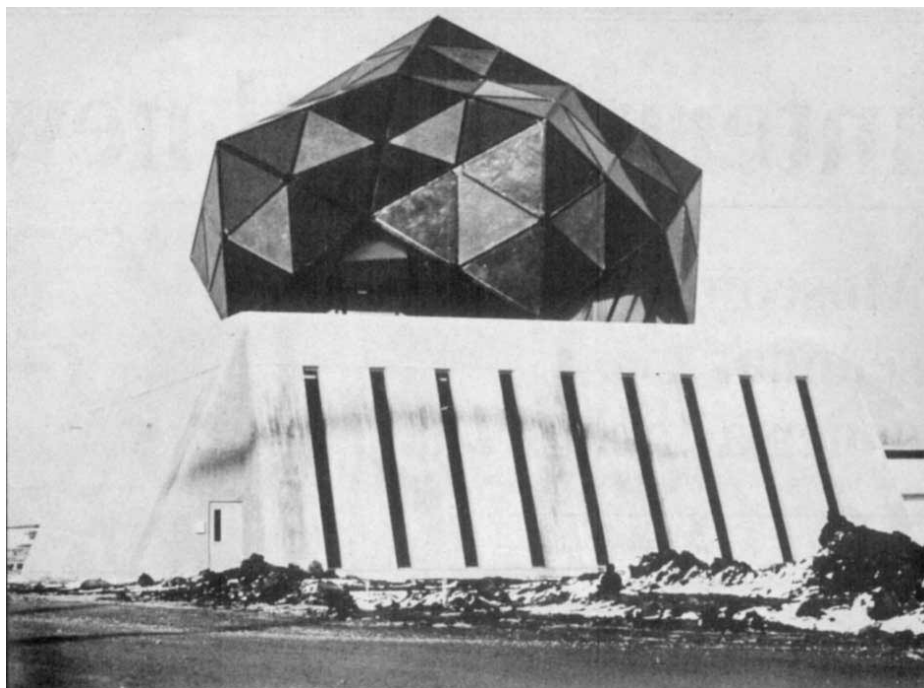
rugated roof of the meson area, and the main building with its trapezoid tower and ground floor forest are all part of a conscious attempt to mitigate the otherwise somewhat featureless Illinois landscape and avoid the standard laboratory concrete block.

Wilson's brave innovations have created problems of their own. One of the least of these is the leaky roof of the meson building, actually made of sections of sewer; what is adequate to contain sewage, it turns out, is not adequate to withstand wind and rain. More serious problems connected with the functioning of the machine itself are candidly documented by Wilson in a recent article (*Scient. Amer.*, **230**, 72; 1974) tracing the progress of the project from its inception until pretty well the moment that the article went to press, when the situation was still changing. At that time, infuriatingly for the scientific community, the proton beam was only operational for about half the time. Moreover, operation at more than 300 GeV threatened to become a source of grievance to the local community by causing a 1% voltage drop in the Commonwealth Edison power lines which feed the machine.

By the time of the dedication, however, the voltage drop had been reduced to within an acceptable 0.5% by means of further capacitors and the accelerator was running at 485 GeV. Better still, it is now operational most of the



The geodesic dome at FNAL: red, white and blue fibreglass panels containing 120,000 'beverage cans' donated by the public.



time and the beam intensity has shifted up from 6×10^{12} to 1×10^{13} protons per pulse close to the goal of 5×10^{13} .

Not that either the teething troubles of the laboratory or its tradition of bold innovation are now at an end. Within days of the dedication ceremony, a new transformer inexplicably failed, setting the machine back to an upper energy limit of 300 GeV for most of the summer. On the other hand, a project budgeted at between \$4 million and \$9 million is under way to test the feasibility of doubling the beam energy yet again. Wilson's path to the tera electron volt would be through superconducting magnets (more new technology), possibly housed within the existing tunnel (more penny saving). So far, because of the technical uncertainties, plans extend only as far as a protodoubler, to be inserted into a small section of the ring through which part of the beam could be run. Experience with the protodoubler should make it possible to gauge the problems of construction, refrigeration and installation of the superconducting magnets, as well as the possible damaging effects of radiation.

Superconducting magnets also enter into plans, still awaiting proton beams and one electron beam approval, for three intersecting storage rings to contain two, and known as POPAE: protons on protons and electrons. But meanwhile, important new phenomena in high energy physics are emerging at an alarming rate from other laboratories, in particular CERN in Geneva and SLAC at Stanford where the last year has seen the first evidence for a unified theory of the weak and electromagnetic interactions (*Nature*, **245**, 119; 1973), and the quark in a curiously paradoxical position—strongly supported by some recent results and equally seriously threatened by others. At this exciting and critical phase in fundamental particle research and with only two years to go before the new CERN accelerator achieves comparable energies, what has FNAL, as the principal sink for high energy funds in the United States, to offer?

The answer lies in the range of high energy secondary particles produced by the collision of the proton beam with its target. FNAL neutrinos and mesons come out at higher energies than those at CERN, and the Batavia synchrotron is the only source of really high energy muons, whose existence as a kind of

massive electron is one of the outstanding puzzles of fundamental particle physics. Colliding beams, which have produced all the surprises, produce secondary particles of only relative low energy.

Many of the most recent results promise to support the efforts of theoretical physicists to find a unified explanation of the four physical forces, and to tie together within some fundamental relationship the embarrassing plethora of particles that comes hurtling out of the nucleus when it is hit with particles of energy more than a GeV or so. But some of the very latest threaten to leave them gasping. FNAL should be in a unique position to fill in the emerging picture in three areas.

The first is that opened up by CERN experiments with a neutrino beam on a stationary target of liquid freon in the giant bubble chamber Gargemelle, where the apparent observation of neutral currents represented evidence for the unity of the weak and the electromagnetic force, as proposed by Steven Weinberg and Abdus Salam. FNAL, with its much higher energy neutrino beam, has already corroborated the CERN result (*Nature*, **249**, 211; 1974) and should now be able to contribute a more quantitative understanding of the phenomenon.

Preliminary data should soon be available on a second question, raised this time by CERN's proton-proton colliding beams. Quite unexpectedly, the interaction probability (or cross section) of the protons, instead of remaining constant, turned out to increase with increasing energy. Investigations at FNAL with other kinds of strongly interacting particle, which seem to be subject to the same non

linearity, will concentrate on the problematic transition energy between constant and rising cross section.

The third question is that of the structure of the hadron: are all the strongly interacting particles made up of combinations of two or three quarks, according to the theories independently developed by Zweig and Gell-Mann? Both the neutrino scattering experiments and the colliding beams of protons on protons say yes, they could be, although the existence of internal structure in the hadron has to be inferred from the distribution of the emerging particles: no force has yet succeeded in ejecting a quark from its nucleon. Both high energy neutrinos and muons are available at FNAL for probing the interstices of the proton in more detail than before, and at a time when experiments with colliding beams of electrons and positrons at SLAC have produced results which stretch quark theory to the limits of its plausibility. The simplest version of the theory (and the pursuit of simplicity is the vocation of the theoretical physicist) predicts a constant ratio of emerging hadrons to muons as collision energy rises. But the SLAC experiment revealed a hadron/muon ratio that increased with energy with no sign of levelling off at the highest reached. Some increase can be accommodated in more complex versions of quark theory, but if the curve goes up any further it will leave even the most elaborate quarks behind.

FNAL should be able to provide the answers to some of the new questions posed by the current spate of exciting and baffling results, and take its place as a focus of scientific, rather than political or administrative, controversy.

international news

Moscow seminar under attack

from Vera Rich

THE latest development in the preparations for the "underground" Moscow seminar on Collective Phenomena and the Applications of Physics to Other Fields of Science scheduled for July 1-5, 1974, has been threats of prison and (or) exile for the 'host', physicist Aleksandr Voronel, and military conscription for a number of participants.

In a statement made by telephone and addressed to the sponsors of the Seminar, the American Academy of Physics, the Royal Society, the association of scientific workers of France, Italy, Germany and other countries, and to the International Society of Jurists, Voronel said that on the morning of June 8, he was "taken by force" by agents of the KGB (in civilian clothes) from near his home and conveyed to the 43rd department of the militia (civil police), where "two hours later, Lt. Col. Anfisov read out to me a warning in the name of the State Security organs", in terms of the decree of the Supreme Soviet of December 25, 1972. This decree has never been published, nor was the text of it shown to Voronel. The warning, however, consisted of the following three points: the seminar is a "provocative measure, pursuing anti-Soviet aims"; holding it will be "in violation of the order existing in the USSR"; and Voronel's actions in promoting the seminar will fall under statute 74 of the criminal code of the Russian Federative Republic: "incitement of national enmity".

This is the first time that so serious an accusation has been levelled at an individual scientist. Previous harassment of Jewish scientists dismissed from their posts as a result of applying to emigrate to Israel has either consisted of charges of "parasitism" (of not being gainfully employed) or else of offences not directly related to their predicament (as in the case of physicist Viktor Polskii, charged with a serious driving offence).

Although Voronel, as the 'host' for the seminar is obviously the prime target, he is not the only participant



personally threatened. Three members of the organising committee: Viktor Brailovskii, Grigorii Rozenshtein and Dmitrii Ram, who are under 40 years of age (the upper limit of liability to conscription) and also two intending participants M. A. Mikulinskii and a certain Khait (no forename available) have been ordered to report for military service. Although their failure to comply with the order renders them liable to criminal prosecution, the conscriptees (whose academic exemption is assumed to have lapsed when they lost their jobs) are, in the long-standing tradition of those wanted by the KGB or its Imperial predecessors, "hiding in the countryside" until July 1 when (if not apprehended in the meantime) they will return to Moscow for the meeting. Mrs Irina Brailovskaya (herself an intending participant) and Mrs Rozenshtein are being subjected, like Voronel himself, to close surveillance by the KGB, in the hope of discovering the whereabouts of the missing men.

Last Thursday it was reported that another committee member, cyberneticist Aleksandr Lunts, had been arrested. The Scientific Council of the Institute of Solid State Physics of the Soviet Academy of Sciences has officially censured the participation of Professor Venyamin Fain and Professor Yakov Yosilevskii for their membership of the Organising Committee. Yosilevskii, hav-

Voronel: threatened

ing already resigned from his post at the Institute, could not be threatened with dismissal; Fain, however, after refusing an order to withdraw from the seminar, was formally reprimanded, which is normally the first step to dismissal. In spite of this pressure campaign, which, following his release, Voronel, in a telephone call to a contact in Israel, described as "unprecedentedly rough treatment", the Committee and the participants from the Soviet Union are still prepared to go ahead.

This harassment of the scientists seems to indicate that the preliminary attacks on the seminar (see *Trud* and *Sovetskay Kultura* of May 17, 1974), which attempted to present it as a "provocational attitude" initiated by the University of Tel Aviv have had little impact, except, as Voronel wryly commented, to give it unhoped for publicity in the Soviet press. In fact, the whole concept of the seminar originated in Moscow, as an almost spontaneous by-product of the summary dismissal from their posts of Jewish scientists who wished to emigrate to Israel. In 1973, a number of scientists who had been sacked in this manner were prevented from presenting their papers at an International Physics Conference in Moscow. They succeeded, however, in making the fact known to the foreign

delegates, and an open invitation was issued to attend an unofficial session in Dr Voronel's apartment, to hear and discuss the banned papers. In all, some 40 delegates attended this meeting, sitting tightly packed upon the floor.

Since that time, the dismissed scientists, in order to foster and preserve some sort of scientific environment for themselves, have been holding regular Sunday seminars. Although representing a wide range of disciplines, from Cybernetics to Sinology, the meetings have, in fact, proved a fruitful source of discussion and interdisciplinary understanding (far more so, perhaps, than the official type of conference in the Soviet Union which, after one or two "plenary" sessions, normally fragments into a number of narrow working groups meeting simultaneously so that virtually no interdisciplinary exchange is possible).

Although a second seminar was later instituted, under the leadership of Dr Grigorii Rozenshtein, dealing with the life sciences (Voronel's original seminar contained a preponderance of mathematicians and physicists), the idea of interdisciplinary exchange has remained a cornerstone of the concept of these seminars. Accordingly, the International Seminar planned for July is not, therefore, in any way an outside interference in the activities of Soviet science. Rather is it an invitation from a group of dismissed scientists—who are, incidentally, only exercising the "freedom of speech" and "freedom of assembly" guaranteed to them by articles 125–127 of the Soviet Constitution of 1936—for their colleagues abroad to participate

in a special 6-day session of the seminar. The three international secretaries of the meeting, Professor Edward Stern of the University of Washington, Dr Norman Chigier of the University of Sheffield, and Dr Raymond Orbach of the University of Tel Aviv are in no way the organisers—they are, as it were, the intermediaries between the would-be participants abroad and the committee in Moscow. Consequently, in spite of the fears expressed by certain scientists abroad for the safety of their Soviet colleagues, the international secretaries cannot take it upon themselves to cancel the seminar—only Voronel and his colleagues in Moscow could take such an action, and this they are resolutely opposed to doing.

In spite of the increasing pressure, which Voronel himself attributes to the "unfortunate" coincidence of the Nixon visit with the date of the seminar, which, he says, has given the authorities an added incentive and "justification" for taking the meeting as a provocation, at the time of going to press, plans are still going ahead. Certain counter measures to the Soviet pressure are in preparation—the submission of letters signed, respectively, by the international sponsors of the seminar and by leading physicists to Dr Philip Handler of the National Academy of Sciences of the USA and Professor W. K. H. Panofsky of the American Physical Society, urging that the bodies they represent should give appropriate consideration to the situation. A conference on high energy physics, to be held at Imperial College, London, at the same time as the

seminar, will be asked to express its solidarity and sympathy. The possibility of formal telegrams to Mstislav V. Keldysh, President of the Soviet Academy of Science, has also been suggested.

Meanwhile, the submission of papers continues: some 120 having been submitted so far, more than 75 of which are from the United States, and including such names as R. A. Dwek (Oxford), D. W. Sciama (Oxford), George Wald (Harvard), John Ziman (Bristol), Sergio Ricossa (Turin), D. Bargeton (Paris) and Peter Hemmerich (Konstanz); the subjects cover a wide range from theoretical cybernetics to medicine, from cytology to the theory of education, and from Marxist sociology to theology.

The intending participants from abroad have made the necessary applications for their visas, and, at the time of going to press, are still awaiting an answer. In the meantime, scientists attending the "official" physics conference in the Soviet Union at the end of June have been invited to stay on for the seminar, as happened last year. In Moscow, the organising committee, under increasing pressure, continue their preparations, and, it is understood, have arranged for alternative venues, should Voronel's apartment become unavailable at the last minute. Although the final outcome remains uncertain, it is clear from the attitude of the organisers, both at home and abroad, that should the International Seminar fail to materialise, it will not be due to any slackening of efforts on their part.

DRILLINGS in the Mediterranean may soon bring the promise of oil self-sufficiency to Israel. Preliminary surveys of the sea bed off Israel's coastline—at the edge of, or just beyond, the continental shelf—have turned up geological structures which may yield oil, according to a statement made last week by the head of Israel's Oceanographic and Limnological Research Company, Yohai Ben-Nun. Ben-Nun, former OC of the Israeli Navy, was reporting on surveys made by his company in cooperation with the Marine Geology Unit of the Geological Institute.

Advanced seismic equipment has already been acquired, added the Admiral, for more exact investigation of these structures and for pinpointing possible drilling sites. While not guaranteeing that oil would be found, he described the anticlinal structures as "very promising indeed". Some of the sites are at depths that make exploitation difficult, given present-day technology, but new techniques being developed elsewhere in the world

Israelis hope for Mediterranean oil

Nechemia Meyers, Rehovot

should make drilling economically and technologically feasible in a few years time.

Meanwhile, plans are going forward for drilling on the continental shelf and on the mainland. Dr Zvi Dinstein, who is in charge of Government oil operations, has announced that IL25 million (£2.5 million)—most of it private capital—will shortly be invested in probes along and just off the Coast Plain from Netanya to the Lebanese border. Surveys are also going on further to the south, particularly in the Gaza Strip area.

Considerable differences of opinion exist in regard to the possibility of striking oil around the Dead Sea. A group of foreign and local investors is reportedly willing to invest millions in drillings there, because, they believe, the asphalt found in the area indicates

the likely presence of oil. Other observers—and geologists—think the asphalt only shows that oil was there, but that this oil has 'migrated' away.

Israel hoped that it had entered the oil era 20 years ago. For in September 1955, regular broadcasts were interrupted to announce that oil had been struck in the Lower Cretaceous sands at Heletz, 35 miles south of Tel Aviv and seven miles east of the Mediterranean coast. Special songs were composed in honour of the occasion and stocks of local oil companies shot sky-high. But production did not live up to expectations. In 1965, at its peak, Heletz and the surrounding fields yielded 202,000 tons of crude oil. Today production is only one-quarter of that figure.

The Six Day War brought Israel access to the Abu Rodeis oil fields in Sinai, which yielded 4.5 million tons in 1973, as against 5.3 million tons in 1972. A further pull back of Israeli forces could cut off that supply of oil altogether, a fact which lends special urgency to drillings in 'old Israel'.

Dear Russell . . . Dear Dixie . . .

by Colin Norman, Washington

A COUPLE of months ago, the Atomic Energy Commission (AEC) received a rude shock from a sister agency in the federal government when the Environmental Protection Agency published a blistering critique of some of the AEC's key justifications for pushing ahead at breakneck speed with the breeder reactor programme. EPA's temerity in questioning some of the arguments made in support of the most important energy research and development programme in the United States evidently hit a raw nerve in the AEC for it has prompted a frosty letter from AEC chairman Dixie Lee Ray to EPA administrator Russell E. Train, and a polite but equally frosty defence of EPA's actions in a reply from Train to Ray.

EPA's critique, which was published on May 4, tore to pieces many of the arguments put forward by AEC in a draft report on the environmental impact of the breeder reactor programme, and EPA gave the report the lowest possible rating of "inadequate". AEC was under court order to put the draft report into final form by June 14, but following EPA's criticisms, AEC sought and received an extension of the deadline. A final environmental impact statement is now expected sometime late in the summer or early autumn.

The dispute between the two agencies could later play an even more important part in the fierce battle now being waged over the breeder reactor, however, for EPA's criticisms may provide the basis for legal action to delay or block the programme by nuclear critics if AEC's final impact statement fails to respond adequately to the points raised by EPA.

But what seems to have offended AEC officials in particular is the manner in which the criticisms were delivered. According to Dixie Lee Ray's letter, the criticisms came as a shock because the two agencies had previously agreed to cooperate in preparing the draft environmental impact statement, and EPA officials had given "repeated telephonic assurances throughout (the) drafting period that there were no problems" with AEC's analyses. "We cannot understand the way in which EPA handled its recent comments" Ray said, and added that "surely there are more constructive ways of handling this and similar situations".

Train replied that although he shares Ray's concern that the two agencies should work constructively together, effective coordination in

producing the statement proved to be impossible, and he said that when differences of opinion arise on impact statements, "our official comments must and will identify these issues and EPA's concerns". In other words Train made it perfectly clear that when his agency believes that another agency in the federal government has produced a poor environmental impact statement, EPA will continue to speak out.

Because of the importance of the fast breeder reactor programme—it is the largest single energy research and development programme in the United States and it will provide the keystone to the entire nuclear power programme in the 1990s and beyond—officials of the AEC, EPA and the White House Council on Environmental Quality met in September last year to try to ensure that the drafting stage of the impact statement would proceed as smoothly as possible. It was agreed at that meeting that AEC would provide EPA with draft copies of chapters of the statement as soon as they were written.

But, according to Train's letter, although AEC supplied EPA with material beginning in December last year, the three most controversial aspects of the statement—those dealing with plutonium toxicity, safety and cost-benefit analysis—were not com-

pleted until February. As far as the cost benefit material was concerned, EPA in fact received no draft at all. Thus EPA had little or no input into those parts of the statement, and as it turned out they were the most heavily criticised parts. Train also pointed out that in the September meeting last year EPA officials identified 14 topics which should be discussed in the impact statement, but only two were addressed in full and five were addressed in part.

Although AEC's pique and EPA's defence of its actions represent little more on the surface than a bureaucratic squabble, they do underline a couple of important points. The first is that with the White House beleaguered by calls for President Nixon's impeachment and resignation, federal agencies are taking an independent line on many issues which would normally be under tight White House control—the EPA, for example, has been taking a stand against several administration policies and several top administration officials have even said in public that they have no fear of White House pressures any more. And the second point is that EPA's independent stand on the breeder reactor statement, which would have been much more difficult in pre-Watergate days, is a vital part of the procedure laid down by the National Environmental Policy Act for ensuring that environmental concerns are taken fully into account in decisions made by the federal government.

Test ban soon?

MR BREZHNEV has now indicated that the Soviet Union is prepared to discuss a ban on underground nuclear weapons tests when Mr Nixon visits Moscow in late June. This together with the continued interest in Washington makes some sort of agreement, even if only an agreement to agree, a near certainty this summer. A treaty is likely to take the form of a threshold agreement in which tests are forbidden only if they produce a seismic signal larger than a specified value. This concept has been strongly criticised in recent weeks; the sort of value being talked about would permit explosions of up to fifty kilotons to be fired if appropriately muffled. A large majority of all tests fired at present are below that level of yield, so the threat to a weapons programme of a threshold treaty could be modest. The speech of Mr Brezhnev does however mention the question of a timetable for phasing out weapons tests entirely, an idea that will be much more difficult to sell to the United States. It will be interesting to see whether the Soviet Union insists on such an addition to any treaty that is signed, as it is potentially embarrassing to the United States and could endanger the talks.

Nuclear safeguards

STUNG by a series of public criticisms of the adequacy of its safeguards against the theft of nuclear materials, the Atomic Energy Commission has elevated nuclear security to a higher position in its bureaucratic hierarchy. The move is, however, unlikely to satisfy the AEC's critics in Congress who are pushing ahead with a bill to force the commission to pay much more attention to nuclear safeguards than it has in the past.

The move consists of amalgamating the present Division of Nuclear Security and the Division of Nuclear Materials Security into a single entity whose job will be to prevent the theft of weapons-grade plutonium and enriched uranium from AEC facilities and in transportation. Critics have long argued that responsibilities for preventing nuclear theft have been fragmented, and so the reorganisation at least helps to answer some of the complaints.

But it falls far short of recommendations contained in two recent studies of the AEC's safeguard regulations, and it also addresses only part of the safeguard problem, for the new division will be responsible only for

THE attacks on Lin Piao and Confucianism in China which began in August 1973 have now spilled over into the pages of *Scientia Sinica*, the distinguished English-language journal of Chinese science published in Peking. In the most recent issue (Vol. 17, No. 2) alongside papers on a Markov description of stationary turbulence, graptoloidea and graptodendroids and pathogens of rice black streak dwarf disease is a section entitled 'Criticising Lin Piao and Confucius; combating and preventing revisionism'. Three testimonies are presented of the absurdity of Confucius' saying 'only the highest who are wise, and the lowest, who are stupid, cannot be changed'. Lin Piao, at one time Mao's Defence Minister and widely believed to have been killed in a plane crash in Mongolia in September 1971 whilst attempting to flee to the Soviet Union, is accused of following Confucius and 'twaddling that knowledge was endowed by nature' and 'slandering the working people as philistines . . . only caring for oil, salt, sauce, vinegar and firewood'.

The first paper, uncompromisingly entitled "'The Lowest, who are stupid' are the wisest while 'The Highest, who are wise' are the most stupid' is by Tsai Tzu-chuan of the Laboratory for Electric Light Source, Shanghai. He was exercised in the early 1960s by the imperialists who gloated over the Chinese incapacity to make a high-pressure mercury vapour lamp. However his group started from scratch and within half-a-year had delivered the goods. This success greatly heightened the morale of the proletariat and smashed the imperialist slander against China: 'advanced architecture but backward lighting'—which, it must be admitted, isn't heard too often these days. One in the eye for Lin Piao who wanted to restore capital-

Anti-revisionism hits *Scientia Sinica*



ism by subjugating the working class to his fascist rule. As Chairman Mao put it 'Lifting a rock only to drop it on one's own feet is the behaviour of a reactionary fool'.

Next Yao Shih-chang of the Tuanchieh Production Brigade, Shantung, relates how Mao's saying that 'correct ideas come from the struggle for production, the class struggle and scientific experiment' is illustrated by his quest for growth of the peanut. His first attempt to raise the yield of his own village's crop of peanuts by importing the methods of a neighbouring village actually decreased the yield and he 'got snubbed'. Next year however he studied the cycle of growth more closely—'I was, so to speak, living together with the peanuts'. Even-

tually by removing earth round the basal parts of peanut plants he found he could raise the yield 25%. This he concludes is the result of not fearing hardships, being bold to practise and ready to get to the bottom of the matter. Lin Piao would not have encouraged this as he thought that the working classes cared only about money, and would have restored landlords. But now millions are clapping hands for joy, so 'let the reactionaries at home and abroad bark what they like.' Finally, Chao Pu-hü, a 'worker-peasant-soldier student' at Kirin Medical College describes his transformation from 'half-baked medical orderly' to 'people's medical officer'. He worked in a deaf-mute clinic and was intrigued by the failure of acupuncture in this field. The books said that there were forbidden zones, and that needles should only be inserted a restricted amount. Chao Pu-hü perceived this as akin to the 'idealist apriorism of Liu Shao-chi, Lin Piao and other swindlers' and proceeded to experiment on himself with prodigious lengths of insertion. This warmed his throat up so he applied the same to a girl Wang Ya-chiu. Three days of the treatment and she called out, for the first time in her life. 'Long live Chairman Mao!' Thus emboldened, he and his colleagues have cured more than 3,000 deaf-mutes in the last five years.

His last colourful words are—'Now those who had tried to check the advance of history as mantis shanks would a carriage were ground to pieces by the wheel of history, yet their reactionary ideology still stinks. We will thoroughly criticise their reactionary world outlook and carry the socialist revolution in the realm of the superstructure through to the end!' And so, on the next page, to a homogeneous denumerable Markov process.

nuclear material contained in AEC facilities, while the AEC's Regulatory division will retain responsibility for safeguarding nuclear material held by the nuclear power industry.

The reorganisation is thus unlikely to disrupt a move, spearheaded by Senator Abraham Ribicoff, to place nuclear security on the same bureaucratic level as the safety of nuclear power plants and to force increased security within the nuclear industry. The move, in the shape of an amendment to a bill designed to split up the AEC into a Nuclear Safety and Licensing Commission and an Energy Research and Development Administration, would create a top-level bureau concerned solely with nuclear safeguards. The bill has now been passed by the Senate Government Operations Committee and it is awaiting full Senate action.

Nature conservation

THE Nature Conservancy Council, having devoted the first months of its existence to internal reorganisation and the task of disentangling itself from the arms of the Natural Environment Research Council, is now ready to turn its attentions outwards again.

At a meeting in London recently, the Director, Mr R. E. Boote, outlined the aims of the 'new' Nature Conservancy. According to the Nature Conservancy Council Act of 1973 the NCC is now required to provide advice to the government on the development and implementation of all policies for or affecting nature conservation in Great Britain. This has enormous implications for the NCC which they intend to take very seriously, now that they are an independent body.

Mr Boote promised that they would not hesitate to make public advice given to the government and disregarded when they felt that circumstances warranted such disclosure.

The NCC continues to manage the 300,000 acres of nature reserves under its control but has relinquished its research stations to NERC. The NCC now commissions the necessary research, mainly from NERC, on the Rothschild customer/contractor principle. When asked whether conflict might arise between the research carried out for the government for NERC and that commissioned by the NCC, Mr Boote replied that as they had complete control over the commissioning of their own research they could always go elsewhere. The NCC is at present financed by a parliamentary grant which this year has been "sufficient".

correspondence

Earth scientists

SIR,—Sir Peter Kent, Sir Kingsley Dunham and Professor Percival Allen charge (*Nature*, June 14) that my article of April 26 was “erroneous and misleading” and “appeared in *Nature* without an attempt to check the facts”. They are quite wrong; indeed in their letter they commit the very sins of which they choose to accuse me, not the least of which is to put into quotation marks an inaccurate version of a phrase I actually wrote.

In my original article I claimed that the General Secretary of the European Geophysical Society (EGS) discovered the planning of the Reading meeting of European geological societies “more or less accidentally”—a claim that Sir Peter and his colleagues attempt to refute by pointing out that the EGS General Secretary was specially informed of the meeting by its organisers. Indeed he was; but the fact is that the meeting had first come to his attention (more or less accidentally, as I said) more than two months before the ‘official’ information was received. Sir Peter and his cosignatories also point out that the EGS President was sent a “special letter” inviting EGS members to participate in the Reading meeting and soliciting topics for discussion. A letter was indeed sent, although in view of the fact that it bears a remarkable resemblance to other letters sent elsewhere, its “special” nature may be doubted.

The most significant aspect of the letter to the EGS President, however, is that the contents of the letter are precisely as Sir Peter and his colleagues describe them—which suggests that the basic point of my article has been missed. No one has suggested that EGS members have not been invited to, or would not be welcome at, the Reading meeting. But what is being suggested is that the organisers of the Reading committee have gone ahead with the first stage of what may well develop into a Geological Society of Europe (GSE) without first consulting the governing bodies of the European earth science societies already in existence, most notably the Council of the EGS.

Sir Peter and his colleagues presumably felt that such consultation was unnecessary. Others, including myself, disagree. For reasons which are too complex to go into here, in both Britain and the United States (and possibly in other countries too) geologists and

geophysicists have come to be associated with different organisations. It is perhaps now too late to change that situation; but in my view it would be a tragedy if a similar sort of separation were to be perpetuated on a European-wide basis. This does not necessarily imply the need for an all-embracing European Earth Science Society, for, as I pointed out in my original article, the problems involved in running such a Society would be almost insurmountable. But what it does mean is the need for close coordination. Geologists may deplore it, but in view of the fact that the EGS already exists the onus must be on anyone thinking, however remotely, about a GSE, to take special care to avoid harmful separation. In return, I feel sure that existing organisations will see the need to modify their own programmes accordingly. In any event, true coordination is much more than simply sending letters announcing a conference.

Sincerely yours,

PETER J. SMITH

Hanslope,

Milton Keynes MK19 7LF, UK

Kidney transplants

SIR,—The article “Transplantation: the failing machinery”, (*Nature*, April 19, 1974) I thought, represented the kidney donor problem in this country very accurately and unfortunately its comments were confirmed by Dr Dudley’s letter (May 31). He was quite right that in the north-west area of London there are no neurosurgical centres, but for years the Atkinson Morley Hospital in the south-west has been the source of many kidneys going to St Mary’s. It should be pointed out that head injuries form only a small proportion of the potential donors. In the south-east only 20% of all kidneys come from patients dying from trauma and less than 5% from a recognised neurosurgical unit. The majority of our donors come from general hospitals and they are by no means always on a ventilator. Indeed, in September, 1973 there was a suitable donor at St Mary’s Hospital, Harrow Road, which was turned down by their Transplant Unit. This year there was a similar case at St Charles Hospital, W10. These kidneys were in fact taken by clinicians from the London Transplant Group and used in the national pool. It cannot be argued that kidneys from these donors were unsuitable for trans-

plantation. In fact I have sent similar kidneys to St Mary’s Hospital and the national pool with good results. Eighty per cent of all kidneys taken in south-east London are from similar donors (60% are not on a ventilator) and 50% function immediately.

As far as potential donors suffering from primary cerebral tumours are concerned, and the fact that they go elsewhere for terminal care, is no reason why those kidneys should be lost to the transplant pool. In Newcastle, all similar patients are put on a donor register and whichever hospital is concerned with their terminal events notifies the transplant team before death.

From my own experience of working in the Casualty Department at St Mary’s, Harrow Road, and from conversations with nurses, housemen and students, it is fairly obvious that there is suitable donor material not being collected in at least one of the hospitals in the north-west area of London. I think that this represents “unequivocal evidence” that there is a lack of understanding and cooperation between doctors which is responsible for the lack of kidneys available for transplantation today.

Yours faithfully,

M. BEWICK

Department of Surgery,

Guy’s Hospital, London SE1 9RT

SIR,—May I make a few comments on Mr H. A. F. Dudley’s criticisms (May 31) of my article on kidney transplants (April 19)?

The figures for the numbers of kidneys received from and contributed to the central pool came from the DHSS Organ Matching Service at Bristol. And having spoken to a number of doctors and surgeons, I was convinced that there was, in some cases, more take than give—and not necessarily because of any variation in the number of cranial trauma patients.

The lack of cooperation between doctors was one of the reasons given by the Royal College of Physicians for the lack of kidneys. I also spoke to a considerable number of hospitals and doctors and found in many cases complete ignorance about the transplant programme and about transplant procedures regarding donor kidneys. And if Mr Dudley wants “unequivocal evidence” surely Mr Barnes’ story is it.

Yours faithfully,

ROBIN LAURANCE

Riverwoods, Marlow, Bucks SL7 1QY

news and views

Collaboration fixes unique QSO spectra

IN these days of proliferating publications, the article which appears on page 743 of this issue of *Nature* is worthy of more than just passing attention. The paper itself is of great significance to astronomers, since it provides some of the first indications of the radio spectra of the QSOs OH471 and OQ172. These are the only radio sources yet definitely identified with optical objects which have redshifts greater than $z=3$, and as such they are, on the cosmological interpretation of those redshifts, the two most distant objects known to man.

The very high redshifts also affect the radio spectra, of course, although the absence of features comparable to the lines in optical spectra makes it impossible to measure the redshift of any QSO by radio observations alone. But in effect by shifting the radio spectra the redshift brings new regions into the band of frequencies which can be covered by radio telescopes based on Earth. Perhaps some of the features seen in these spectra are, then, typical of features which would be discovered at rather shorter wavelengths

in the spectra of QSOs with smaller redshifts.

In the excitement caused by the identification of these objects, it would surely have been natural to expect everybody with access to a radiotelescope to make observations and rush them into print. The result would undoubtedly have been a scattering of reports in various journals, causing much adrenalin to be produced by other frustrated radio astronomers desperately trying to keep up with 'the literature' and to find some overall picture of the radio spectra of the two QSOs.

But in fact a different approach has been adopted. Contributions which might have formed the basis of ten separate short notes here, there and everywhere have been combined in the one article we are publishing today. The degree of international cooperation involved is notable even for astronomy; as a result this paper provides in one place just about all that needs to be said (at this stage) about the radio spectra of OH471 and OQ172. *Nature* is always happy to cooperate in ventures like this which both reduce the number of separate papers we have waiting to be published and, we hope, provide a service to the scientific community (see, for example, the Cygnus X-3 issue of *Nature Physical Science*, **239**, 113–136; 1972).

JOHN GRIBBIN

Origin of plasmacytoma cells

THE DNA polymerase activity known as terminal deoxynucleotidyl transferase has been reported in murine plasmacytoma cells, with interesting implications for the study if tissue differentiation (see page 775 of this issue of *Nature*).

Terminal deoxynucleotidyl transferase differs from the other known DNA polymerase activities in mammalian cells in that it catalyses the addition of deoxyribonucleotides to the 3'-OH end of preformed polynucleotide chains in the absence of a DNA template. Although this effect has been useful as a model for the mechanism of polymerisation (*Proc. natn. Acad. Sci. U.S.A.*, **65**, 1041–1048; 1971) and for end group labelling of deoxyoligonucleotides (*Eur. J. Biochem.*, **22**, 271–276; 1971), the biological function of the enzyme is unclear, and it has been suggested that it is a degradation product of DNA polymerase. But its role as a marker for the origin and state of differentiation of certain cells is an interesting possibility.

The terminal transferase activity was first isolated in calf thymus, and has since been demonstrated in the thymus of numerous animals, but in no other tissue. Thus the activity seems to be entirely tissue specific, and also shows a development cycle which arises early in the process of embryonic development and persists in the thymus of young and adolescent animals.

McCaffrey *et al.* (*Proc. natn. Acad. Sci. U.S.A.*, **70**, 521–515; 1973) have found that cells from a patient with childhood acute lymphoblastic leukaemia (ALL) contain an enzyme with the properties of terminal transferase; this suggests that these tumour cells are thymic cells blocked very early in differentiation. Furthermore, the ALL cells lacked detectable surface immunoglobulin, a characteristic of

thymocytes. No activity was found in normal T-cells (thymus-derived lymphocytes), nor in three cultured human cell lines. This suggests that the enzyme was a marker for true thymocytes and provides hopes that an assay of this DNA polymerase might provide a diagnostic marker for whether a given leukaemia is of thymus or bone-marrow (bursal) origin.

Now Penit, Paraf and Chapeville have found that terminal transferase exists in murine plasmacytoma cells. This finding is surprising since these tissue-cultured cells have been thought of as B-cells (they express the immunological properties of cells derived from bone marrow). If the presence of terminal transferase activity in a cell is truly indicative of a thymic origin, then it would not be unreasonable to suggest that plasmacytoma cells represent an intermediate stage of differentiation between B and T cells. As Penit *et al.* point out, this has a precedent in a cloned line of thymoma (thymic tumour) cells produced by irradiation in mice. The thymoma cells possessed the T-cell characteristics of θ -antigen and anatomically thymic origin, and the B-cell characteristics of readily detectable surface immunoglobulin and immune complex receptor activity.

Unfortunately it is not yet possible to be certain that the expression of terminal transferase is evidence of an intermediate state of differentiation in plasmacytoma cells since immunological data are lacking, especially with regard to thymus antigens. A synthesis of immunological and biochemical approaches may elucidate the origin of cells containing terminal transferase activity and determine whether this will have diagnostic uses.

TONY PAWSON

Minor tyrosine genes of major importance

THE structure and function of transfer RNA are so well understood that it is surprising how little is known of the transcription of this RNA and of the genes from which it is transcribed. This is partly due to the difficulties involved in isolating the tRNA genes which are scattered through the genome in small clusters.

Unless the tDNA is chemically synthesised, it is only possible to obtain DNA enriched in tDNA genes, rather than pure tDNA. For example, using the DNA of a species of mycoplasma enriched so that the tDNA is 10% of the total, it has been possible to show that uridine is converted to pseudouridine post-transcriptionally. Forming hybrids between total cell DNA and tRNA has given some information about the size of the genes and supports the idea that the genes for tRNA are grouped together in twos or threes. But by far the most informative method has made use of the transducing bacteriophage $\phi 80$. This phage has an attachment site (in *Escherichia coli*) near the two minor tyrosine genes which together contribute 30% of the total tyrosine tRNA. The two genes are indistinguishable except in su_{III}^+ cells where one of them—the suppressor gene—has a single base change in the anticodon region, which allows tyrosine to be read instead of the terminator codon UAG.

When the phage carrying one or other of the two minor tyrosine tRNA genes is transduced into *E. coli*, large amounts of tyr tRNA can be detected in the post-infection phase. In mutants in which this amount of RNA is reduced, it was found that this was because the processing of the RNA was less efficient, leading to an accumulation of the first transcription product. Using $\phi 80$ carrying one of the minor tyr tRNA genes (the suppressor mutant), the accumulated RNA was examined by Altman and was shown to contain some 40 nucleotides more than the mature tyr tRNA (*Nature new Biol.*, **229**, 19; 1971). Subsequent sequencing of the molecule by Altman and Smith (*Nature new Biol.*, **233**, 35; 1971) revealed several interesting features of this tyr tRNA precursor. It seems that, like the mature tRNA, the precursor also has a 'clover-leaf' secondary structure but differs from it in that bases modified on the active tRNA are unmodified in the precursor. The authors also present evidence that mutations which alter the amount of mature RNA produced are close to the point at which the precursor molecule is cleaved.

Chysen and Celis have used one of these mutations—one which reduces the rate of synthesis of su_{III}^+ tyr tRNA—

to determine whether the two minor tyr tRNA genes are transcribed into one large precursor or two separate ones (their results are described in *Nature*, **249**, 418; 1974). In this case it was necessary to infect *E. coli* with a transducing phage carrying both su_{III}^+ and wild type tyr genes. They reasoned that if the two genes are jointly transcribed then a mutation which affects the rate of transcription of the su_{III}^+ gene should also affect the rate of transcription of the wild type gene.

The experimental approach made use of the separation of tyrosine tRNA from bulk tRNA obtained by polyacrylamide gel electrophoresis. Once eluted from the gel the ^{32}P -labelled tyrosine tRNA was subjected to RNase T_1 digestion. Characteristic T_1 fragments identified tyr_{II} tRNA (the major species) and the two minor species tyr_I su_{III}^+ and tyr_I wild type. By comparing the relative amounts of tyr tRNA I and II mutations which reduced the amount of tyr_I tRNA were identified, and those which reduced the level of su_{III}^+ tRNA also reduced the level of wild-type tRNA. It seems therefore that the two genes are transcribed into one single precursor tRNA. Confirmatory evidence of this was obtained from an analysis of the RNA synthesised, after infection with $\phi 80$ carrying both minor tyr genes in cells deficient in RNase P (RNase P is the enzyme which cleaves the precursor to form the mature tRNA). The bands obtained by electrophoresis of the RNA were eluted and digested with RNase T_1 . Of the fingerprints obtained there was none characteristic for a 'singlet' precursor of the wild-type tRNA.

Knowing that the two minor tyrosine tRNAs are transcribed together, it becomes particularly interesting to have some information concerning the structure of the genes. This is provided in an article in page 738 of this issue of *Nature* by Landy, Foeller and Ross, although at the time of writing the existence of the 'doublet' precursor was not fully established. Their approach was to compare the DNase digestion pattern of phage $\phi 80$ (parental) with $\phi 80$ su_{III}^+ (singlet—the suppressor gene) and with $\phi 80$ su_{III}^+ (doublet—the suppressor gene and the wild type). Limited digestion with site-specific nuclease endo R. *Hind*, followed by electrophoresis under different conditions, led to complete resolution of all the fragments. Most of the fragments were the same for all three RNAs of course, but three fragments were unique to the parental $\phi 80$; one fragment was unique to the singlet, one to the doublet, and five fragments were found in the singlet and doublet but not in the

parental phage. These last fragments did not form hybrids with mature tyr tRNA and so their transcript may be that part of the precursor which is cleaved during tRNA biosynthesis. It seems that the size of one tRNA gene plus any unduplicated intergenic sequence is approximately 200-260 base pairs—about two or three times the size of tyr tRNA. The authors suggest a maximum of 125 base pairs for the intergenic sequence between the duplicated genes. Further sequencing of the DNase fragments will allow these figures to be more accurately assigned and provide a complete analysis of the tyr tRNA gene(s).

PAMELA HAMLYN

Alpine tundra change after road building

from Peter D. Moore
Plant Ecology Correspondent

ALPINE tundra habitats are simple in structure, yet often diverse in species. The species which can survive under such rigorous climatic conditions are of considerable biological interest because of their elaborate phenological and physiological adaptations (see Billings and Mooney, *Biol. Rev.*, **43**, 481; 1968). Their extreme adaptation to climatic stress may render them particularly susceptible to hardships of other kinds, such as human interference. A short growing season results in low productivity and this means that recovery following disturbance is bound to be slow.

Bell and Bliss (*Biol. Conserv.*, **5**, 25; 1973) studied regeneration of vegetation on areas laid bare by road construction in Olympic National Park, Washington, and found that after more than 30 years plant cover was still very low. Greller (*ibid.*, **6**, 84; 1974) has now produced similar data from Rocky Mountain National Park, Colorado. In this park two roads provide easy access to an open expanse of alpine tundra; one of the roads was constructed in 1920 and the other in 1932, but recolonisation of the verges, laid bare by construction activities, has been very slow.

Greller found that north-facing slopes had become dominated by *Poa fendleriana*, and south-facing slopes by *Agropyron scribneri*, both of which are tussock-grass species, well adapted to growth on unstable soils. It is a matter for concern that these slope communities are low in diversity and lack many of the more interesting

species of the tundra vegetation, but Greller's conclusion that succession plays only a minor part in these situations cannot be justified from his data. Fifty years is a relatively short time in the history of most successions and under the extreme climatic stress of alpine habitats one might expect even slower developmental rates. The current lack of vegetation can hardly be construed as proving a lack of successional development. Natural periglacial soil processes must surely act in an equivalent fashion to produce similarly denuded slopes.

Greller's suggestion that succession may be curtailed by soil dryness on the artificially steepened slopes of the banks is not likely to be correct. Many alpine species have xeromorphic adaptations, and Teeri (*Science*, **179**, 496; 1973) has found that *Saxifraga oppositifolia* can withstand water deficits as great as -55 bar. Drought is unlikely to prove a serious hindrance to the growth of alpine communities. Soil instability may slow down or even divert the course of succession, but one cannot assume that this is the case after only 50 years.

Nevertheless, one is faced with the fact that habitat disturbance caused by road building leaves scars upon the tundra landscape which may take many generations to heal and which, indeed, may never heal at all. This consideration should occupy a position of importance in the minds of those responsible for the routing of such highways. An additional problem is that of trampling pressures by those who gain access to the tundra along the highways. Alpine vegetation is particularly susceptible to this additional stress, as has been demonstrated in the Cairngorm mountains of Scotland, where the provision of easy access to the public (by roads and a ski lift) has led to ever-widening paths and trampled soils (see Watson in, *The Biotic Effects of Public Pressures on the Environment*, edit. by E. Duffey, Natural Environment Research Council, London; 1967). It may be that the instability of roadside slopes in the tundra areas of Rocky Mountains National Park will be one of the least concerns of its conservators.

Blastokinin induction by steroids

from our
Steroid Biochemistry Correspondent

SINCE the identification in rabbit uterine fluid of a specific protein blastokinin or uteroglobin, much research has been carried out to define the precise physiological role of this compound. It appears in uterine fluid

after ovulation and its concentration is high at the time of implantation. One of the effects of the protein is to stimulate the transition of the morula to the blastocyst, a transition, however, which will also occur *in vitro* without blastokinin provided some other protein which will bind progesterone is present. Addition of progesterone to culture media containing blastokinin stimulates RNA and protein synthesis by the embryo and blastokinin may function as a binding protein for steroids which may be needed by the embryo. Blastokinin will not only bind progesterone but also seems to be controlled by progesterone.

The control of this protein by progesterone and related compounds has been investigated by Arthur and Chang (*Fert. Steril.*, **25**, 217-221; 1974). Steroids were administered to rabbits daily for 5 d post-oestrus; 24 h later the animals were killed and the uterine fluid was examined by Sephadex column chromatography for the presence of blastokinin. The protein was detected in rabbits treated with progesterone and the 17α -acetoxyprogesterone, chlormadinone acetate and medroxyprogesterone acetate. The amount of blastokinin in uterine fluid was similar after treatment for 5 d with these steroids to that found on the fifth day of pregnancy. These progestogens are known to have a spectrum of biological activity similar to progesterone whereas the other group of orally active progestational compounds related to 19-nortestosterone have a different spectrum of activity; these latter compounds, as well as oestrogens, were ineffective in inducing blastokinin.

The relation between steroid structure and blastokinin induction merits further investigation because the inducing effect of some of these steroids may be related to their contraceptive action. It is now recognised that the hormonal contraceptives owe their high efficacy to effects at a number of sites in the reproductive process and contraceptive efficacy can be obtained with doses of synthetic steroids which do not inhibit ovulation. Arthur and Chang suggest that administration of steroids during the pre-ovulatory phase of the cycle may change the uterine environment by induction of specific uterine proteins so that it will no longer support embryonic development and/or implantation. Furthermore it might be possible to develop compounds which have this effect but which would be without the adverse side effects associated with some of the hormonal contraceptives currently used. The idea is attractive but so far blastokinin has not been demonstrated in human uterine fluid.

The topologist meets the biologist

from a Correspondent

A MEETING on May 21-24 organised by the Mathematics Institute of the University of Warwick and sponsored by the Science Research Council was intended to initiate a dialogue between biologists, mainly in embryology and neurophysiology, and specialists in differential topology and dynamical systems.

The possibility of such a dialogue owes much to the efforts of C. H. Waddington (University of Edinburgh), R. Thom (Institute des Hautes Etudes Scientifiques, Paris) and E. C. Zeeman (University of Warwick). Waddington has for many years stressed that topology is a natural language for developmental biology. Thom sees his catastrophe theory as an essay towards an algebra of morphology, enriching the range of our ways of describing and classifying forms. His talk at the Warwick meeting was euphoric, aphoristic, enthralling and exasperating in turns.

Zeeman has taken on the task of convincing biologists, by means of concrete applications to problems they see as important, that catastrophe theory can be predictive. The reaction to his talk on amphibian gastrulation suggested that a fruitful dialogue has begun. A sequence of talks on development—by P. D. Nieuwkoop (State University of Utrecht), D. Ede (University of Glasgow), J. Cooke (National Institute for Medical Research, Mill Hill), J. Lewis (Middlesex Hospital Medical School, London) and P. Shelton (University of Leicester)—could have left the mathematicians in no doubt about the fascination and complexity of the regions into which they are venturing.

At other points the meeting turned more to debate between biologists, notably in a marathon session on hardware and software in perception, involving principally D. Marr (University of Cambridge), W. R. Adey (University of California, Los Angeles) and D. Sunday (California State University). It seemed that the brain is not ready for the topologists or that they are not ready for the brain.

One session was devoted to problems in which differential equation models have traditionally been used. Handling solutions of coupled ordinary differential equations as trajectories is an essentially topological procedure. So it seems very likely that the power and scope of models for interacting animal species, chemical oscillators and circadian rhythms can be greatly extended. In this session A. Winfree (Purdue University) revealed how illuminating it can be to apply topological reasoning to circadian rhythms and to travelling waves in chemical reactions.

Convection in a layered mantle

from Peter J. Smith
Geomagnetism Correspondent

SEISMIC data have revealed that the Earth's upper mantle contains several discontinuities in density and seismic velocity, the most prominent of which lies at a depth of about 650 km. But what constraints does the existence of such discontinuities place on the form and magnitude of the convection currents which are believed to share the same region of upper mantle space? The full answer to this question would depend on a complete knowledge of the nature of the transitions producing the discontinuities—a matter which is far from being resolved. Insofar as the discontinuous changes in physical properties are due to mineralogical phase transitions they are relatively well understood; and their effect on convection is probably quite small. Richter (*Rev. Geophys. Space Phys.*, **11**, 223; 1973), for example, has shown that the Rayleigh–Benard convection driven solely by unstable vertical temperature gradients, the presence of the olivine–spinel phase transformation does not alter the structure of the flow and produces a roughly two-fold increase in steady amplitude. But if, in addition, chemical changes are involved, the problem changes because the position of the critical boundary will depend not on state parameters but on advection.

The question of whether or not the mantle is chemically inhomogeneous is still a matter of debate, although there must be a strong presumption in its favour. Press (in *The Nature of the Solid Earth*, McGraw-Hill, 1972), for example, investigated bulk sound velocity as a function of density for a set of Earth models obtained using Monte Carlo techniques and concluded that an offset in the velocity–density plot near the 650 km phase transition represents an increase in the Fe/Mg ratio. Several other workers have reached similar conclusions, although such agreement is not necessarily as impressive as it seems because there are known to be certain problems associated with the determination of mean atomic weight using bulk velocity–density data. Moreover Wang (*J. geophys. Res.*, **75**, 3264; 1970) has shown that it is possible to find an Earth model with a chemically homogeneous upper mantle which is quite consistent with free oscillation data. Anderson and Jordan (*Phys. Earth Planet. Interiors*, **3**, 23; 1970), on the other hand, support iron enrichment of the lower mantle using several methods which are apparently not open to the objections directed at bulk velocity–density systematics.

In summary, then, chemical stratification in the upper mantle, though not proven, is highly likely; and so it is important to investigate what effects such layering is likely to have on convection processes. Richter and Johnson (*J. geophys. Res.*, **79**, 1635; 1974) have now attempted to do this by analysing the stability, to heating from below, of a system comprising two immiscible fluid layers of different density separated by a boundary which will be advected by the flow. What emerges from the fluid dynamical analysis is a stability diagram for the system showing the critical Rayleigh number (that is, the critical value of the normal Rayleigh number, R_a) for the most unstable mode as a function of R_ρ , the Rayleigh number based on the density contrast between layers. In other words, the stability diagram is a curve in R_a – R_ρ space which separates the stable region below (towards lower R_a , R_ρ values) from the unstable region above (towards higher R_a , R_ρ values). In this context, stability means that at a given point in R_a – R_ρ space all perturbations decay with time.

For R_ρ lower than about 5×10^3 , the most unstable mode is a standing oscillation on the interface between the two layers (overstable mode); and once the oscillatory motion begins, the fluid never returns to a state of total immobility. This overstable regime only exists within a very narrow band of R_a values, however, suggesting that its occurrence is not very probable. Below this band (lower R_a) the system is stable, but above it (R_a higher than about 10^4) direct convection throughout the entire depth of fluid (that is, throughout both layers) becomes possible. If such convection were actually to take place it would, of course, destroy the original chemical layering; conversely the persistence of a chemical boundary precludes total-depth convection. For R_ρ higher than about 5×10^3 the situation is quite different. In this region the most unstable mode comprises separate convection within each layer and is thus independent of the density jump across the boundary between the layers. The stability curve separating the stable and unstable regions in R_a – R_ρ space is now parallel to the R_ρ axis, and so the stability or instability of the system depends only on the value of R_a .

These results place important bounds on acceptable Earth models. If the overstable mode is ruled out as improbable, for a model in which R_ρ is lower than 5×10^3 the occurrence of convection is consistent with the continued presence of a chemical boundary because the convection would cross the boundary and chemically homogenise the system. Thus in a model in which both convection and chemical

layering are inferred, R_ρ must be higher than 5×10^3 —and in this case there will be separate convection within each layer. In the case of the real Earth, much therefore depends on whether the 650 km discontinuity is just a phase change or whether it represents the combined effect of a phase transformation and a chemical change. Assuming that a chemical change is indeed present and that it involves an increase in iron relative to magnesium, several authors have calculated that R_ρ would be of the order of 10^6 . This clearly implies that convection may only occur separately above and below a depth of about 650 km.

This result does much to emphasise the importance of resolving the problem of whether or not the upper mantle is chemically inhomogeneous. The convective motions for seafloor spreading are likely to be those in the uppermost layer, and the thickness of this layer will influence the magnitude of the convective cells within it. Richter (*Rev. Geophys. Space Phys.*, **11**, 223; 1973), for example, showed that many of the possible flows in the mantle have horizontal scales comparable with the depth scale. The fact that the depth scale may be governed by the presence of chemical layering clearly makes it necessary to determine whether or not such layering actually exists.

Modeling tide and surge interaction

from J. Darbyshire

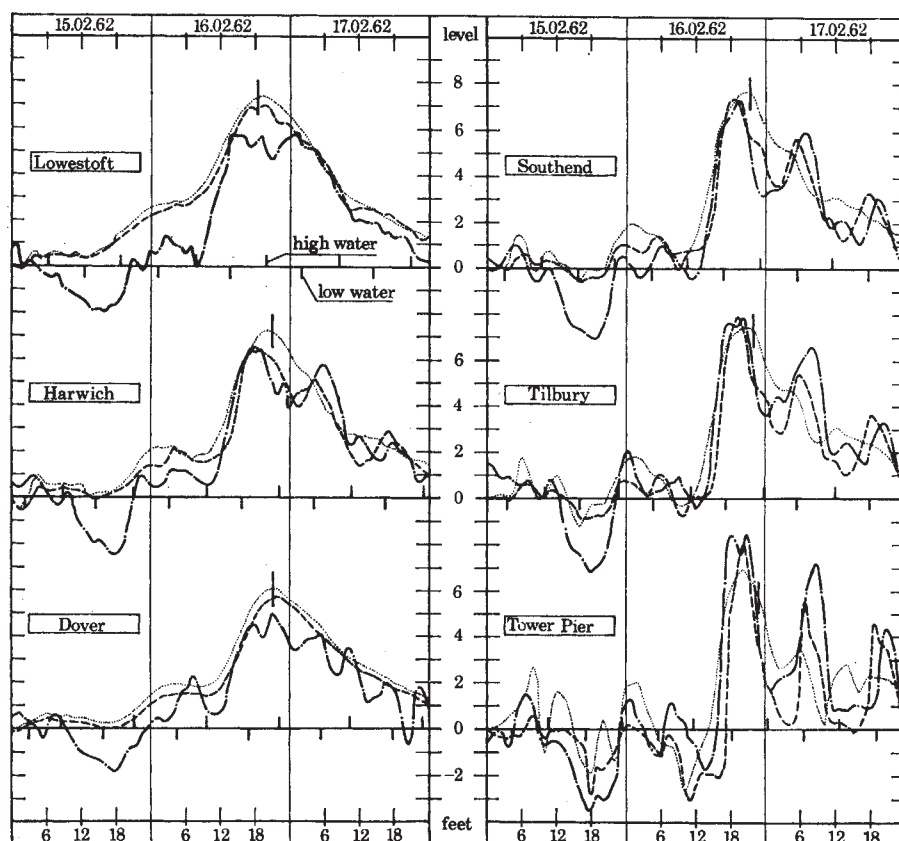
GREAT disasters and natural upheavals often provide an incentive for scientific research and this has been very true in the investigation of storm surges (or the extra tides caused by meteorological effects). The first such stimulus was probably the great Thames flood of 1928 which led to the systematic recording of these effects at Southend and to work on their prediction at the Bidston Observatory near Birkenhead. The methods originally used were largely empirical and the work of Doodson and Corkan was very important during this period.

The next great stimulus was the disastrous flooding of the English east coast and the Dutch coast during January 31–February 1, 1953, when many lives were lost and many of the Dutch dykes were seriously breached. After this there was set up at the British Meteorological Office, a flood warning system which made use of the fact that tidal abnormalities on the English side of the southern North Sea are usually preceded by similar smaller but detectable abnormalities at Aberdeen about 9 h earlier. This would give an even longer warning to the continental

coasts. The 1953 surge also led to a spate of research. Rossiter published an article in the *Philosophical Transactions* which described very accurately the abnormalities at various times at all the ports on the circumference of the North Sea where tidal records were available. These results led to further attempts to improve methods of prediction and I was involved with one of them (J. and M. Darbyshire, *Proc. R. Soc.*, **A235**, 260–274; 1956). Hansen of Hamburg, on the basis of these observations, produced (*Tellus*, **8**, 287–300; 1956) the first mathematical model based on the use of digital computers and achieved a very high measure of success. The storage capacity of computers of this period were, however, rather too limited to cope with the hundreds of equations involved in finite difference methods and Ishiguro of the National Institute of Oceanography devised methods based on an electrical analogue of the North Sea which were to prove very useful (*Storm Surges in the North Sea—An Electronic Model Approach*, report 4, paper 25 (iii), Advisory Committee on Oceanographic and Meteorological Research; 1966).

The research effort in Britain, however, was still largely centred at the Liverpool Tidal Observatory at Bidston (later on to become the Institute of Coastal Oceanography and Tides and now a part of the Institute of Oceanographic Sciences) and the lead of the late J. R. Rossiter in this field will always be remembered. The work was extended to river estuaries, particularly the Thames, but it soon became evident that there was a large interaction effect between tide and surge which could not be ignored. Proudman had already predicted this on theoretical grounds. A computer model of the Thames based on these considerations was produced by Rossiter and subsequently Rossiter and Lennon. Models of the North Sea had ignored this interaction effect, but a new article by Joyce Banks, also from Bidston, extends the river model into the southern North Sea and allows for the effect of tidal interaction (*Phil. Trans. R. Soc.*, **A275**, 567–609; 1974).

Banks confines the investigation to the period of the notorious Hamburg surge of February 1962. In the figure is reproduced part of one of her diagrams which shows a comparison of observed surge effects at various English ports with predictions based on her model both with and without allowance for tidal interaction. An examination of the results shows that the tidal effect is very small in the open sea and the only appreciable difference is at Tower Pier. The initial negative surge is not successfully predicted and this is probably due to its being caused by conditions outside the southern North Sea and not accounted for by the model.



Time variations in wind-induced sea levels of the Hamburg surge at British ports. —, Observed residual elevation after removal of the barometric surge; ---, surge level ξ_{51} computed on the basis of wind and tide; . . . , wind surge ξ_5 computed in the absence of a tide. Times of high and low water of the total predicted tide are marked along the abscissae. The vertical line near the peak surge corresponds to the time of high water of the computed lunar tide.

It seems a very far cry from the early empirical days to the modern highly sophisticated computer methods, yet a prediction of the surge at Lowestoft for February 1962, based on my very simple formula published in 1956, compares very favourably with that storm in the figure and as the formula took some account of conditions in the northern North Sea, the results do show a slight initial negative surge. Empirical methods, although very useful from a practical point of view, do not, however, help a great deal to gain a fuller understanding of the fundamental processes involved.

Randomness in evolution

from A. Hallam
Palaeontology Correspondent

HISTORICAL events can be studied in two radically different ways. Each individual event can be considered on its own merits, and interpreted independently, or many such events can be dealt with collectively, with a view to formulating general laws. The first type of approach can be termed idiographic

and the second nomothetic. All historical events have both idiographic and nomothetic aspects, but palaeontologists have traditionally focused on the former. With regard to the major question of evolutionary diversification and extinction of particular fossil groups, a wide variety of patterns has been recognised, but little success has been achieved in attributing these to specific causes or in creating general models with predictive power. Consequently several American workers have recently adopted the nomothetic approach, to test the possibility that some aspects of the evolutionary record behave as stochastic or random variables. Each event may depend on the joint occurrence of many underlying genetic, morphological, physiological and ecological causes but the event itself may only be predictable statistically, even though it has a conventional cause. The analogy of the gas laws in physics comes to mind, with each fossil taxon playing the part of individual gas molecules.

Van Valen, in the first number of a new journal called *Evolutionary Theory* (July 1973), tackled the problem of faunal extinctions by applying the

survivorship curve technique of population ecology, which is a simple plot of the proportion of the original sample that survives for various intervals of time. The use of a logarithmic ordinate ensures that the slope of the curve at any given age is proportional to the probability of extinction at that age. Van Valen's analyses of numerous taxa showed almost uniform linearity in the survivorship curves, allowing for sampling error. This is rather surprising, because it requires that the probability of fossil discovery does not decrease appreciably with the age of the strata, as has been argued by Raup in an article in *Science* (117, 1065; 1972); also because, for living taxa, both constant origination and extinction rates are implied. Van Valen is led on to propose a new evolutionary 'law', that extinction in any adaptive zone occurs at a stochastically constant rate. Exceptions to the 'law' are considered to be either spurious, rare or doubtful. He also proposes a new unit to measure the rate of extinction, the macarthur, named after a well known American evolutionary ecologist.

Raup, Gould, Schopf and Simberloff adopt a different approach in the *Journal of Geology* (81, 525; 1973) to the more general question of diversification and extinction, by using a computer to generate phylogenetic diagrams, or cladograms. The lineage of each clade, or monophyletic subunit, was generated by the computer program and caused to terminate or branch in order to produce a hypothetical phylogeny, with the termination and branching events being stochastically controlled using random numbers. Part of the input dealt with the establishment of an equilibrium diversity, in accord with modern evolutionary theory. The cladograms so produced exhibit a great variety of shapes: some underwent early exponential increase in diversity and then declined gradually to extinction (the trilobites); others showed a gradual diversity increase followed by a rapid extinction (dinosaurs) or passed through a near-extinction phase to develop a new phase of high diversity (ammonites). The average extinct clade increases in diversity up to the mid point of its stratigraphical range and then declines in diversity until extinction. When faced with such variation in pattern many palaeontologists have been inclined to suspect or postulate that the organisms in question were inherently different in evolutionary potential. The observed variation does not exclude, but nor does it demand this. Comparison with a real example, the fossil record of the reptiles, shows good general agreement but also some interesting differences. Thus the late Cretaceous extinctions showed more coincidence between different groups

than predicted from the computer model.

It seems therefore that an exceedingly simple stochastic model can produce branching and diversity patterns very similar to those described in the real world; also that the taxonomy utilised by palaeontologists imposes various constraints similar to those used in the logic of the computer program. The question arises, where does one go from here? In the first place palaeontologists should be even more suspicious of any glib deterministic explanation of the diversification and extinction of any particular fossil group. More positively, there is a more sophisticated tool for investigating the extent to which the coincidence in time of extinction of different fossil groups departs from randomness. This should be easy to demonstrate for the striking mass extinctions at the end of the Permian and Cretaceous, but what of the other geological periods?

Two dimensional rotons

from Peter V. E. McClintock
Condensed Matter Correspondent

A ROTON in a two-dimensional assembly of helium atoms has a smaller energy than a roton in three dimensions, according to a calculation by Padmore of Erindale College, University of Toronto (*Phys. Rev. Lett.*, 32, 826; 1974).

The thermodynamic properties of bulk liquid helium below its superfluid transition temperature can be understood reasonably well on the basis of a model, due to Landau, in which it is assumed that the thermal energy is all in the form of a gas of particle-like excitations moving through the superfluid, which plays the part of an inert background or aether. There are two main types of excitation: phonons, which are quantised sound waves much like those occurring in solids; and rotons, which are peculiar to liquid helium and are believed to correspond to some sort of stirring motions on the atomic scale, such as microscopic vortex rings. There is, as yet, no agreement as to the precise physical nature of rotons, but their detailed energy-momentum relationship, known as the excitation spectrum, has been established through neutron scattering experiments and is consistent to a high precision with the measured heat capacity of the liquid.

Although attempts to deduce the excitation spectrum theoretically from first principles for an assembly of weakly interacting helium atoms have not been very successful, Feynman and Cohen (*Phys. Rev.*, 102, 1189; 1956)

managed to derive a spectrum of the correct general shape and approximately in quantitative agreement with experiment, by using quantum mechanics. Their approach involved to a considerable extent the use of physical intuition to develop a wave function able to describe the superfluid background, and they then used a so-called trial wave function, not specified in detail, in order to describe the elementary excitations. A variational method was used to investigate how the trial wave function should be modified in order to minimise the energy of the whole assembly, and thus discover the true wave function from which the excitation spectrum could then be derived. Padmore has extended the Feynman and Cohen approach in an attempt to derive theoretically the excitation spectrum of a two-dimensional (2D) assembly of helium atoms.

Assemblies which are effectively 2D occur where one of two atomic layers of helium are deposited on a solid surface. The helium atoms are held in place by the attractive Van der Waals force which prevents them from moving in a direction perpendicular to the surface; but they can remain completely free to move parallel to the surface. Under appropriate conditions of density and temperature, such assemblies have been shown to form either 2D crystalline solids, or liquids, or gases. By using, for the substrate, materials such as exfoliated graphite or Vycor glass which have very large surface areas in relation to their volumes, it is possible to measure the heat capacity of 2D liquid helium, and experiments have shown that the heat capacity appears to be anomalously large. A possible explanation lies in the idea that rotons can still exist in a 2D assembly, but with smaller energies than they have in 3D. A neutron scattering experiment to measure the excitation spectrum does not seem possible because of the random orientations of different sections of the substrate, so a calculation of the spectrum is therefore of particular interest.

The most important conclusion which emerges from Padmore's calculation is that the energy of a roton in 2D is indeed considerably less than in 3D. Although the calculated roton energy, is, as in the 3D case, still somewhat larger than would be consistent with the measured heat capacity, the change in energy in going from 3D to 2D seems to be in excellent agreement with the relatively few experimental data at present available. Padmore also reports his calculated characteristics for rotons in 2D helium at a number of different densities, so no doubt there will soon be reports of further experiments aimed at checking these more detailed conclusions.

Accurate spectroscopic factors

from Peter E. Hodgson
Nuclear Theory Correspondent

DURING the past ten years the one-nucleon transfer reactions have been developed into one of the most powerful tools for studying the single-particle aspects of nuclear structure. Among these the (d,p) reaction has been most widely used, but extensive studies have also been made using (d,n), (p,d), (d,t), (d,h) and many similar reactions that either add a proton or neutron to or remove one from the target nucleus.

As a typical example, consider the (d,p) reaction on ^{24}Mg . The incident deuteron interacts with the ^{24}Mg target and deposits a neutron in one of the unoccupied neutron states, and the remaining proton goes on alone. At lower energies this process can take place by absorption of the deuteron to form a compound nucleus followed a long time after by proton emission, but at higher energies the direct process that takes place in a time comparable with the time taken by the deuteron to cross the target nucleus predominates to such an extent that the compound nucleus process is negligible.

The differential cross section for this direct (d,p) reaction can be written as the product of two factors, one depending only on the structure of the nuclei involved and the other only on the reaction mechanism:

$$[d\sigma/d\Omega] = S_{JL} F_{JL}(\theta, E)$$

All the dependence of the cross section on the angle of emission θ of the proton and on the incident deuteron energy E is contained in the reaction factor $F_{JL}(\theta, E)$, and this can be calculated by the distorted wave theory. These angular distributions are in general characteristic of the total quantum number J and orbital angular momentum quantum number L of the state entered by the captured neutron so that comparison between the observed angular distribution and those calculated for various J and L enable these quantum numbers to be determined, and these give the spins of the corresponding states of ^{24}Mg .

The spectroscopic factor S_{JL} is a measure of the single-particle strength of the neutron state and is given by the ratio of the measured cross-sections to the calculated value of the $F_{JL}(\theta, E)$.

The analysis is thus able to give the quantum numbers and the single-particle strengths of all the nuclear states of ^{24}Mg reached by the reaction. Numerous analyses of nuclear states in all stable nuclei have been made with this technique, and it is one of our main sources of information on nuclear structure. The main limitations to this method are, first, that it is not always

possible to determine J and L and, second, that the uncertainties in the distorted wave theory make the spectroscopic factors uncertain to about 20%, even in the best circumstances.

A new method of analysing one-nucleon transfer reactions has now been proposed by C. F. Clement of Harwell (*Nucl. Phys.*, **A213**, 469 and 493; 1973) and used to obtain more reliable J, L and more accurate spectroscopic factors. This method depends on the j -dependent sum rules that relate the spectroscopic factors of the reactions that remove a neutron (or proton) from a nucleus to the spectroscopic factors for the corresponding reaction that adds a neutron to the same nucleus. The j is the total angular momentum of the transferred nucleon. These sum rules provide a rigid set of equations that must be satisfied by the spins of the final states and by the spectroscopic factors of the corresponding transitions.

These sum rules must be distinguished from the more familiar J -dependent total sum rules that relate the spectroscopic factors to the total single-particle strengths of the states. The j -dependent sum rules provide additional constraints on the spectroscopic factors only if the spin of the ground state of the target nucleus is different from zero; if it is zero they are the same as the total sum rules. The method is thus applicable only to nuclei with ground state spins different from zero. All these sum rules were derived long ago by J. P. French, but it is only recently that they have been applied to nuclear structure analyses.

Clement and Perez (*Nucl. Phys.*, **A213**, 510; 1973) have now applied this analysis to the reactions (d,t) and (d,p) that remove neutrons from or add them to the states of ^{44}Sc with spin $7/2$. The sum rules give a set of eight equations connecting sixteen sums of spectroscopic factors for stripping and pick-up to states of different spin. The measured spectroscopic factors satisfied these equations to an accuracy of 4% in relative magnitude and 10% in absolute magnitude. Several additional spin assignments to states of the residual nuclei ^{44}Sc and ^{44}Sc were made by this analysis.

An important problem in all analyses of single-particle states is the fraction of the strength that is far removed from the main concentration. Clement and Perez find that it would be difficult to maintain their fits to the sum rules if more than 10% of the total is in the continuum. Thus nearly all the $f_{7/2}$ strength is concentrated in a limited energy region; this is an important conclusion for the basic single-particle model of nuclear structure and supports the validity of the distorted wave theory.

Subsequently Clement and Perez have applied the sum rule analysis to other nuclei and have still further reduced the uncertainties in the absolute spectroscopic factors. This is clearly a technique of great power that can provide valuable information on nuclear structure and stringent tests of the present techniques for obtaining it.

Fitting the flower to the bee

from a Correspondent

WITH the increasing use of F_1 hybrids in insect-pollinated agricultural crops and vegetables, special methods have to be devised to get enough effective pollinating insect visitors to achieve the complete cross fertilisation that is necessary. At the Third International Symposium on Pollination organised in Prague from May 15-18 by the International Commission for Bee Botany of IUBS, the Bee Research Association and the Academy of Agricultural Sciences and other bodies in Czechoslovakia, examples discussed included red clover, lucerne, field bean, melon and cucumber. A detailed knowledge of floral biology, pollen and nectar production, and their composition is needed; for instance, Ing. H. Haslbachová (College of Agriculture, Brno) reported success in increasing pollination (and hence seed yield) in tetraploid red clover by applying growth regulators which alter the morphology of the subsequent flowers in ways which make them easier for the bees to work.

Visitation by bees is necessary for good crops of strawberries from some cultivars, and L. J. Connor (Ohio State University) has found that the number of visits a flower receives depends on its structure. Flowers with stamens short in relation to the receptacle are difficult to work and not much visited. Unfortunately the first flower on a stem (giving the earliest, most profitable, fruit crop) has short stamens, even in cultivars whose later flowers have long stamens. Here the most likely solution is breeding plants for floral morphology that suits the pollinating bees.

G. D. Waller (US Department of Agriculture Laboratory, Tucson), in seeking to find out why it is difficult to achieve adequate pollination in onion seed plots (*Allium cepa*), found that honeybees—the major pollinator—are unwilling to forage on the onion flowers. The only difference between these flowers and others available nearby is that the potassium concentration of the onion nectar is about ten times as high as that of other nectars. An interspecific hybrid *Allium cepa* $\times$ *A. fistulosum* produces nectar with a normal potassium

content and is very attractive to honeybees. These results provide the first evidence that a minor constituent of nectar can significantly inhibit its collection by honeybees.

Much less is known about pollination in the tropics than in temperate regions, though an even higher proportion of tropical crops probably depend on insect pollination. S. E. McGregor (USDA Laboratory, Tucson) presented a list of 120 such crops, belonging to 39 botanical families. T. Chandler, a Canadian currently working at the Forestry Training Institute, Arusha, Tanzania, has studied pollination of lucerne by the African honeybee *Apis mellifera adansonii*, which has come in for much reprobation recently on account of its aggressive (or defensive) behaviour. This subspecies proves much more effective than the European ones at 'tripping' the flower, and thus pollinating it, largely because lucerne pollen is attractive to them, whereas other pollens are preferred by European honeybees. Also, the African honeybees are efficient at detecting which florets are at the right stage for tripping, and thus do not waste time visiting those that were too immature.

Work by Mackensen and Nye on breeding *Apis mellifera* specifically for collecting pollen from lucerne has now been successfully extended to red clover by H. Nørgaard Holm in Denmark (Højbakkegård, Tåstrup).

Since the second pollination symposium in London in 1964, commercial rearing of certain species of soil-nesting and stem-nesting bees has progressed beyond all expectation. Reports came of work in Canada, United States, France, Hungary, Czechoslovakia and other countries. From Poland L. Borunus and his colleagues (Beekeeping Institute, Pulawy) brought news of the highly successful rearing of bumblebees for pollination, achieved largely by careful determination of these bees' preferences at each stage of their seasonal cycle.

In an account of the first 25 years of the Bee Research Association at Chalfont St Peter, Buckinghamshire, Eva Crane reported that a 23-year index to research reported in its journal *Apicultural Abstracts* (1950-1972) has just been completed. The information is stored on magnetic tape, and it is hoped to publish it as author and subject catalogues, linked to abstracts in the journal. The 17,000 publications represented include many giving information on pollination, and a volume *Pollination of Seed Crops*, based on publications reported in *Apicultural Abstracts*, has already appeared. Estimates of the world value of crops resulting from insect pollination vary from £1,000M to £10,000M a year or more.

Gap junction between cells in contact

from a Correspondent

ALL cells in tissues and all but two of twenty-five cultured cell lines form junctions with one another and communicate through these junctions by transfer of electrical signals and chemical substances (the latter was originally termed metabolic cooperation). The junctions form extremely rapidly, within a minute certainly, and presumably break just as rapidly. Cells therefore are constantly forming and breaking contacts for metabolic cooperation and intercytoplasmic exchange. The relevance of such processes to inductive interactions during tissue differentiation and embryogenesis makes this one of the newest and perhaps most interesting areas in biology. The Cell Surfaces Discussion Group held a timely meeting on May 23 at the National Institute for Medical Research, Mill Hill on the structure and function of intercellular junctions.

The particular consideration of the meeting was the gap junction between cells in contact, permitting the flow of matter across the membranes between two cells. E. L. Benedetti (Institute of Molecular Biology, Paris) catalogued interesting similarities and differences between the propagation of an electric current between cells and passage of chemical tracers. Thus both electric coupling and chemical transfer are bidirectional and operate across the same junction. Some separation of these events is implied, however, since the former is present in most embryonic cells, excitable and non-excitable, and there may be some restraint of chemical transfer in embryonic tissues.

The inability to form gap junctions is also seen in some cell lines such as L fibroblasts, for example, and this is recessive in cell hybrids. Thus, heterokaryons with human fibroblasts can electrically and chemically couple and revertants that lack part of the complement of human chromosomes first lose competence for passage of chemical markers across the gap junction and subsequently the capacity for electrical coupling.

The types of chemicals transported across gap junctions is quite wide, but, as was emphasised by J. Pitts (University of Glasgow), there is an upper molecular weight limit of about 1,000. The flux of a metabolite, such as a purine nucleotide, is calculated to be about 10^3 – 10^6 molecules s^{-1} across the gap junction, that is about equivalent to the *Escherichia coli* chromosome. The capacity of mouse fibroblasts to form gap junctions may not be lost irretrievably and it is pos-

sible to select for 'revertant' cells that form junctions, but not as efficiently as say BHK cells.

E. Wright (Institute of Virology, University of Glasgow) described experiments that set out to isolate BHK cell mutants incapable of forming competent junctions. The basis of the selection is to cocultivate BHK wild type cells with a thymidine kinase negative mutant and BUdR and to isolate cells which survive ultraviolet irradiation. Interestingly, although these mutants (*Mec*⁻) as expected are extremely poor recipients of thymidine from a BHK wild type cell population, metabolic cooperation can be established if a purine marker such as adenine is used so that there seems to be discrimination between the passage of two nucleosides across the gap junction.

As both Pitts and Wright agree, the idea that the many metabolites capable of passage across the gap junction may require independent transport processes is extremely difficult to reconcile with the evidence that purified gap junctions appear to contain relatively few proteins. For example, W. H. Evans (National Institute for Medical Research, Mill Hill) finds one major protein of molecular weight 29,000 in fractions of mouse liver plasma membranes enriched in gap junctions. Similar results were reported for synaptic junctional complexes by I. Morgan (Centre de Neurochimie, CNRS, Strasbourg) and A. Matus (University College, London). The most common method of preparation, however, involves detergent solubilisation of the non-junctional areas of membrane and it may be that some dissolution of junctional membrane components may also take place.

The mechanism of formation of gap junctions remains obscure. Since junctions can form in the absence of protein synthesis, pre-existing membrane proteins are utilised. The junctional areas, however, are clearly differentiated from the rest of the membrane by the absence both of typical enzyme markers such as 5'-nucleotidase and leucyl naphthylamidase and most of the plasma membrane proteins and glycoproteins. It must be assumed, therefore, that the initial events in junction formation requires the clustering of specific junctional proteins by lateral diffusion in the surface membrane.

The association of cytoplasmic contractile elements with gap junctions now seems established. One supportive result is the probable identity of an actin-like protein in preparations of mouse liver gap junctions. The role of these elements in formation maintenance and function of the gap junction, however, remains to be elucidated.

energy review

How Britain is facing the energy problem

"Our energy strategy must be flexible, balancing between different fuels and different sources, steering between overcaution and recklessness." Mr Eric Varley, Secretary of State for Energy, gives his view of the situation.

THIS edition of *Nature* devoted to energy matters is very timely. The problems which we face in this field are complex and far-reaching and, as Secretary of State for Energy, I am concerned that they should be as widely understood and thought about as possible. My department was set up in the midst of crises and its first six months have inevitably been preoccupied with the transition to greater stability. But we are now tackling the problems—many of them pressing—of the longer term. Public discussion of the problems involved is very important, particularly among scientists and technologists whose contribution to their solution can be very great.

The broad context of these problems is familiar. Consumption of energy on a large scale is part of the fabric of our society. Last year Britain consumed the equivalent of 342 million tons of coal, with oil (159 million tons of coal equivalent) and coal (131 million tons) the largest components: and in the past every extra 1% of GDP has been accompanied by increased energy consumption equivalent to about two million tons of coal. We have to plan far ahead to continue to meet these needs as securely, flexibly and cheaply as possible in a way which allows continuing economic growth. But whereas our consumption patterns reflect past access to cheap and plentiful supplies of energy, we must now accept that energy is an expensive commodity; that more active policies are needed nationally and internationally to achieve security and availability; and that much more attention needs to be paid to the way we use our energy, cutting out waste and improving efficiency.

Coal and oil

Development of our indigenous resources must be a key factor in our strategy. It is already apparent that these resources are very substantial and that, though we still do not know their full extent, they can make a very major contribution to our energy supplies and, more broadly, to the strength of our economy. But there is a wide range of important and testing problems to be solved in bringing them forward and in making the best possible use of them.

We have much the biggest coal industry in western Europe, despite its decline during the past decade or so, and the new energy situation has completely altered the framework in which its future is planned. It is already clear that coal must remain one of the main foundations of our energy policy and that the industry can look forward to a sure future. But a lot of work has to be done to ensure that its contribution is made most effectively. Just holding annual production from deep mines at its present level of around 120 million tons—and I hope to go above

that if possible—will be a major task. One of my first acts on coming into office was therefore to announce the setting up of a full scale examination—involving government, the unions concerned, and the National Coal Board—of the contribution which coal can best make to Britain's future energy requirements and of the steps needed to secure this contribution. Good progress has been made and we hope we will have made an interim report by the end of this month.

Then there are all the resources of the North Sea. North Sea gas already supplies 90% of our gas consumption; and North Sea oil offers the prospect of a completely new source of oil supply, with all the advantages that that implies in the present world energy situation. It also offers us challenges, both in its development and, having brought it ashore, in making the best use of it. Nowhere else in the world has oil been brought up from these depths in these conditions, and great technological and engineering skill has to be brought into play to make sure that development proceeds as fast as possible. I am concerned not only to see that this feat is carried through successfully but also to develop policies which will ensure that oil and gas from the Continental Shelf are exploited in such a way as to confer maximum benefit on the community, particularly in Scotland and the regions elsewhere in need of development.

Nuclear prospects

Another major and difficult area is nuclear policy. Studies in depth and extensive deliberations about nuclear reactor choice have been in hand literally for years, without any clear consensus emerging. It is certainly an area of great technological complexity where the issues are not at all easy to weigh up. At the time of writing I have not come to, or announced, any decision. But I would stress that it is clear that there is no ideal solution.

The implications of the new energy situation are of course far reaching and certainly not confined to the problems of developing indigenous resources and nuclear power, and planning to meet long term demand. Many other issues are involved. One which I believe will, and must, increasingly impinge on the lives of everyone is the conservation of energy in the sense of cutting out unneces-

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sary consumption and improving efficiency in use. Energy is now an expensive commodity and this fact alone will bring home to many people the need to use it thriftily. But the government has a role to play too, and this is another area where I want to do what I can to speed up and encourage adaptation to the new energy situation.

In every one of the areas which I have mentioned the role which science and technology must play is of great importance, in many instances fundamental. Indeed it is no exaggeration to say that science and technology must provide the key to the longer term future. And, because of the time scales involved, we have to be very farsighted in our approach. Well directed and effective decisions on research are therefore an essential part of energy policy.

There can be no doubt that the main thrust of research and development on energy in this country must continue to be nuclear, looking towards the fast breeder reactor and then, we hope, towards the very long term prospect of controlled nuclear fusion as an energy source. Nuclear technology is by far the most promising avenue to pursue, in terms of meeting the energy needs both of the United Kingdom and of the world as a whole. We are therefore investing substantial sums in the nuclear field and are actively seeking international collaboration to ensure rapid advance at minimum cost. I recognise the misgivings which some people have about the safety of nuclear power. It is a matter to which I attach the greatest importance and I recognise my responsibility to uphold the very high safety standards which have been established in Britain.

Other possibilities

Nuclear power is not of course the only possible option. Readers of the technical press will be familiar with a wide range of other possibilities being championed: for instance 'natural' sources, using energy from the Sun, tides, wind, waves and geothermal heat. But the development costs of these different technologies are likely to be high. We already spend more than £100 million each year in the United Kingdom on energy research and development, and we do not have unlimited resources. Moreover we should not feel that the United Kingdom must develop every technology for itself; in many cases international collaboration makes good sense and in some cases the best course may even be to import the developed technology.

Engineers and scientists in my department have examined the whole range of these other technologies in the energy sector which we might back, and, in collaboration with other departments, they have made detailed studies of the most promising options. They have paid attention to the possible scale of each technology in relation to our energy needs, the cost and time for development, and the possibility of successful exploitation, as well

as to the likely impact on the environment. Their conclusion has been that none of the various possibilities shows sufficient promise to warrant large scale investment in research and development at this stage. It has to be remembered that many of these new sources would be in competition with nuclear power, as a source of electricity, and not with fossil fuels; so that their attractiveness in economic terms is not affected one way or the other by the rise in oil prices.

Nevertheless, this is an area where assessment is a continuing process. I have, for instance, felt that some further work on recurring energy is warranted as a form of insurance policy and I have accordingly commissioned a more detailed study of the prospects of extracting energy from sea waves: wave power is not expected to compete economically with nuclear power but it is an energy source particularly suited to the United Kingdom, with surprisingly large potential. I have also recently set up a team of scientists and engineers at Harwell to examine the many technological options and to ensure that our conclusions are soundly based. I recognise the importance to our future energy supply of getting these conclusions right.

We must adopt a quantitative approach to the big and far reaching decisions that have to be taken over the whole field of energy. Primary weight has to be given to the normal economic tests; energy is not the only scarce resource and an economic appraisal—provided we use realistic prices and, where necessary, take account of resource costs—enables resources of many different kinds to be weighed in the same scales. We know, of course, that these tests never tell the whole story. The calculations are only as good as the assumptions on which they are based. And we must have at the back of our minds other more nebulous considerations; with some, like security of supply, satisfactory quantification may be difficult, and with some, like the needs of future generations for energy supplies, it may be virtually impossible. But we must take the best account of them we can, while bearing in mind that, if we do decide to go down paths other than those indicated by the economic tests, we must be clear we are doing so for good and sufficient reasons.

Finally we must face the problem of taking decisions involving very long time scales. Over a long period the whole framework can change radically. On occasions it may change abruptly, as it did for oil last October. We are, therefore, very much in the business of risk taking. Not only can we not be sure that we have the answers, we cannot even be sure that we know the problems. It is for these reasons that our energy strategy must be flexible, balancing between different fuels and different sources, steering between overcaution and recklessness. However much any of us may think that we have the right answer, we cannot know for sure.

Towards rational energy policies

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"It is nonsensical to treat coal, gas, electricity, oil and nuclear energy as separate fuels without regard to the overall needs of Britain, and that is what has happened up to now. We should set up a National Fuel and Power Council to develop a coordinated and comprehensive policy for all the industries concerned".

It was in 1957 that I was involved with a small group of people, including some distinguished scientists, in having a look at, amongst other things, the future policy for energy for the United Kingdom. We had then, of course, no knowledge of what was going to come nearly twenty years later, but we did make that declaration and nothing that has happened since has shaken my belief in it. In fact the recent events in the Middle

East, which brought the western world almost to its knees and certainly quadrupled the price of oil, has strengthened my conviction of the importance of a permanent Energy Commission; its terms of reference today should be to make the United Kingdom completely independent of energy supplies from abroad at the earliest possible date.

North Sea gas and North Sea oil, which will begin to come into Britain very shortly, are additions to the other available energy sources that we have, the main one of course being coal, with nuclear power moving up. It is now generally accepted that the rundown of the coal industry during the 1960s was a grievous error. We made ourselves more and more dependent on outside sources for our energy requirements and not only handed over to the Middle East oil-producing countries control of our industrial production, but added considerably to our balance of payments problem. We now have the opportunity of complete independence and excellent energy export prospects. But this has to be carefully planned, because the relationship between coal, nuclear power, North Sea gas and North Sea oil should be so arranged as to maximise the life of oil and gas, while the opportunity is provided for nuclear power to make a gradual increase to the energy requirements of the nation.

First, I believe we must begin with the coal industry and ensure that its size is no longer dominated by the price factor, which determined its future from the latter part of the 1950s to date.

There should be established a target output for coal for the next 20 to 30 years. Coal production means long term planning. There is not only the question of planning the exploitation of the reserves and the constant replacement of the reserves to make good the annual extraction, but also the much more difficult and sensitive problem of planning for manpower requirements over several generations ahead. This involves immense human problems and social problems and cannot be adequately planned unless there is a guaranteed annual output.

There are two things that are absolutely essential if one is to maintain energy independence for all time—energy planning independent of Whitehall and international research on energy resources. The present method of planning by the Civil Service within a department is hardly likely to succeed. There must be serious doubts about the efficacy of the present machinery in Whitehall for resolving the kind of problems that emerge when one is considering four suppliers of energy, and the contribution that each have to make over the years ahead, and the life expectancy and economics of each of those sources of energy. If the government were wise, it would set up an Energy Commission right away to oversee the whole energy field and be responsible for advising ministers on strategy and tactics. If the Department of Energy decides to produce an energy policy from its own resources, it will assuredly fail as miserably as its predecessor failed with the Energy White Paper of 1967. The resources of the ministry are inadequate to do the enormous task of this long term planning.

The Civil Servants concerned with the writing of the 1967 policy are no longer there to face the consequences of the impotence of the 1967 White Paper. Some are retired, some are engaged elsewhere. The Civil Service approach to problems lacks continuity, and this is an inadequate approach. No *ad hoc* consideration can possibly perform the task of a continuing review. What is needed is an Energy Commission, whose task it would be to advise the government on energy policy and undertake comprehensive studies. The commission would be a continuing authority, staffed by experts in fuel economics and the specialist technologies. The commission, having no particular axe to grind, would be able to produce objectively an energy policy planned entirely in the national interest. It would do the total sum, taking into account all the knowledge now available as to the quantities of indigenous gas, oil and coal, and the expected contribution of nuclear power.

It would be able to ensure that capital investment was

directed into those channels of energy development that would give the best return in national terms, rather than in a narrow advantage of one fuel over another. The infighting between the publicly owned energy industries would cease, as their place in the energy pattern would be properly established. Only an independent Energy Commission, in my view, would get the juxtaposition of coal, gas, electricity, oil and even nuclear energy about right. In an imperfect world, we cannot expect perfection although we can strive towards it; but like everything else, striving without the right tools would be a near hopeless task. An independent Energy Commission would be the right tool to do the job. There can be no doubt that such a commission would be able to create the plans and oversee the direction of those plans so as to provide the United Kingdom with independent sources of energy by the early 1980s.

The second very important approach must be to endeavour to secure an international research team into energy resources. Some time ago President Nixon set out on this trail, but I think failed because he invited too many countries to be involved. What I think is important is to set up an International Energy Council, whose purpose would be to mobilise the necessary teams for research. The object of the international research team would be to examine the possibilities of solar heat, oil and gas from coal, and oil from oil shale and tar sands. In these areas lie vast quantities of energy and although a good deal of the technology is already known, and makes a good starting point, a substantial amount of extra research work is required which is both costly in money and requires a very large group of fuel scientists and technicians. There is already a wide variety of work going on in Britain and in America to devise new routes for synthesising chemicals, oil and gas from coal. Research work in Britain has been concentrated on the development of the solvent extraction of coal and on digest extracts primarily as a route towards producing low volumes of high value and specialised products from coal. In America the basic theme of this work has been to apply solvent extraction and existing hydrogenation and other refining techniques to the synthesis of crude oil and natural gas as bulk sources of energy of raw materials.

These differing approaches have been dictated by the rather different relative economics of the coal and oil industries on either side of the Atlantic and by markedly different views about the security of petroleum supply.

Twenty-five years ago American energy planners had grasped the significance of the imbalance between gas and oil consumption and reserve availability. Historically the route towards chemicals and gas from coal has lain in coking. A typical feature, however, of traditional gas production from coke is the low calorific value—about 600 BTU per cubic foot—of the resultant product. Further notable features were the need for gas and coke markets to be in volume balance, and the highly fragmented localised nature of the coke-based gas-making industry enforced by maximum economic sizes of coke production units. In contrast, the discovery of natural gas has created a demand for gas of high calorific value, rich in methane, distributed from a relatively small number of sources through a trunk pipe line system.

As the years of North Sea gas begin to tail off, some quarter of a century from now, and where the demand for gas increases beyond economic production rates from North Sea sources, it will be necessary to synthesise what the Americans so aptly call pipeline gas, which can be blended in with North Sea supplies.

Already then we can see by an examination of the research work of the United States, and what is being done in Britain, that there is a great area of common knowledge and certainly a unified desire to retain energy independence. I believe, therefore, that it is highly important to press hard for international research work in these fields. There can be no doubt that the research scientists on both sides of the Atlantic will reach conclusions far quicker by working together than if they work independently.

The summary of my conclusions is, therefore:

- To reach complete independence for energy at the earliest possible date, and certainly not later than the early 1980s.
- To have an Energy Commission to advise the government on the way in which this objective can be achieved.

- To seek the greatest measure of international cooperation on research into the whole field of energy resources and energy uses in order to ensure that, despite the increase in energy demands year by year, world requirements of energy will be readily available.

North Sea oil in a world context

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Dr F. Howitt, of BP, assesses the oil and gas reserves which Britain can expect to exploit from the waters around its coastlines. Although supplies are limited, there seems to be some room for optimism: even if no more oil is discovered there may still be a small supply at the beginning of the next century.

DESPITE the fact that not a drop of indigenous regular production oil has reached UK shores from the North Sea, many people, myself included, are counting chickens. I want to put the results which have been obtained so far into the context of the present and potential production of the rest of the world. My statements and predictions are based on information collected by myself and my colleagues in the British Petroleum Company Limited.

Our conception of the general geological framework of the North Sea area is illustrated in Fig. 1. This shows the basins of sedimentation which developed after peneplanation following the Variscan orogeny (at the end of Carboniferous times) and which played the major role in providing the source and reservoir potential for most of the oil discovered so far. A conceptional cross-section illustrating stratigraphical succession, with major structural elements, relative thicknesses and current exploration 'plays' is shown in Fig. 2. Only very major faults and folds are illustrated, and Zechstein salt movement is idealised. The section is, however, drawn to scale particularly through chosen boreholes, although there is a vertical exaggeration of 60. The line of section is meant to go up the central median region, but in order to show major oilfield types it has been necessary to offset in places.

Occurrence of reservoirs

Despite the heavy exploration effort, during which 275 boreholes have been sunk since 1965 in the southern North Sea Basin, and the consequent discovery of some 42×10^{12} cubic feet of gas reserves, discoveries continue in the Permian Rotliegendes Sandstone. This is the same reservoir as that in the Leman Bank Field¹. The gas is probably derived from the carbonisation of the coal in the underlying Coal Measures², and the structures are mostly sealed by overlying Zechstein salt³. One major gas discovery—the Hewett field—produces gas from two levels of Trias sands, in a structure that provided no seal at Zechstein level for the escaping Carboniferous gas. Naturally, the development of Rotliegendes sand facies to form the pre-Zechstein reservoir is a crucial general factor. Glennie⁴ has argued plausibly that the reservoir sand formed essentially as a result of

wind deflation of alluvial fans which spread northwards from the Variscan mountains.

Drilling in the northern North Sea Basin (about 200 exploration wells since 1969) has shown that three major 'plays' exist. The first is in the BP Forties Field, where there is oil in the Palaeocene sandstones⁵. This also seems to be the case in the nearby Montrose Field. Gas and condensates reportedly has been found also in the Tertiary sandstones of the Frigg, Heimdall and Cod Fields. The second 'play', which was the first to be discovered, is oil from the domed and fractured Upper Cretaceous and Danian chalks in the Ekofisk group of fields in Norwegian waters⁶, and in the Dan Field in Danish waters. The third 'play' is oil from both the Jurassic sandstones in the far northern waters, where the Brent Field was the first discovery, and apparently

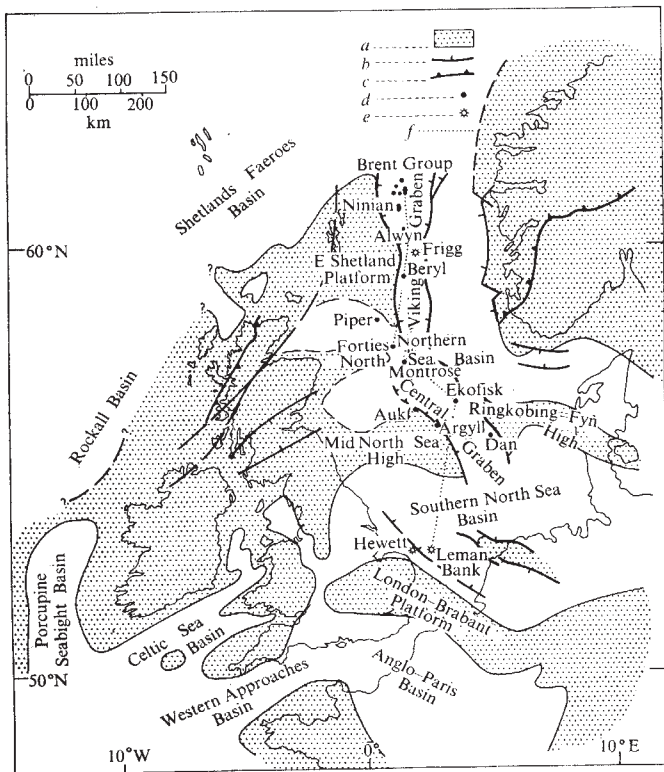


Fig. 1 Sedimentary basins around the British Isles, and the North Sea geological framework since the end of Carboniferous times. a, Stable pre-Permian areas; b, major faults; c, thrust faults; d, oil fields; e, gas fields; f, line of section of Fig. 2.

from the Moray Firth Basin, where Piper Field has been discovered. A further but smaller series of fields seem to be associated with older Palaeozoic rocks where they come into contact with unconformable Cretaceous rocks.

One striking fact revealed by the map of the location of all these oil discoveries, is that they lie within, or close to the edge of, the central, down-faulted area. The fault system is more complex than the simple graben representation (Fig. 1). Tensional and collapse forces developed throughout Middle and Upper Jurassic times after a regional central uplift. The tension was accompanied by volcanicity, mostly of Bathonian age, with at least one centre just to the north of the Forties oilfield. Individual fault blocks remained as positive areas until the end of the Cimmerian movements, after which most of them were covered by Cretaceous sediment. Relative upward movement continued in several instances, however, and some of these structures have uppermost Cretaceous resting on early Mesozoic or even older rocks. This major and complex unconformity is responsible for trapping the oil of the northern area in the underlying structures of Jurassic or earlier rocks. Fortunately, within the Viking graben, the Cretaceous overlying the unconformity is an almost continuous shale and mudstone facies, unlike the ubiquitous chalks of the south. Whether the hydrocarbon source is also in part the Cretaceous shales at the unconformity, or whether it is from indigenous Jurassic shale, is not certain. All of the oils, however, whether from Palaeocene, Cretaceous, Jurassic or earlier reservoirs, have similar properties. The sulphur content is of a low order—

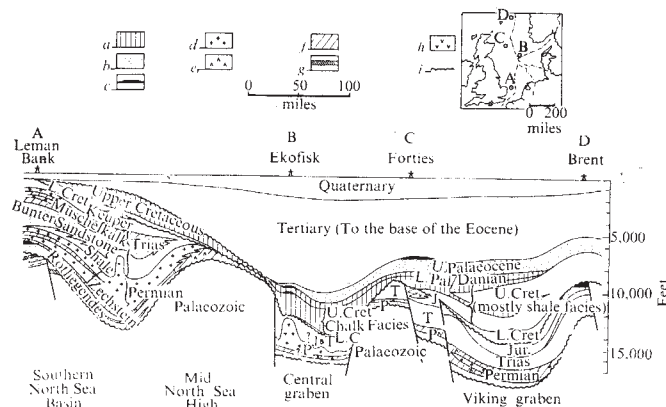


Fig. 2 Generalised and diagrammatic cross section (see Fig. 1) of the North Sea, from the Leman Bank gas field (south) to the Brent oilfield (north). *a*, chalk; *b*, sand or sandstone; *c*, oil or gas field; *d*, halite; *e*, anhydrite; *f*, dolomite; *g*, Coal Measures; *h*, volcanics; *i*, major unconformities. The horizontal scale is shown; vertical exaggeration $\times 60$.

0.2–0.9% by weight—and asphaltenes are about 0.3–0.6% by weight. Gravities are in the high range (35–44° API, with most restricted to 35–37° API). Wax content is fairly high at 6.5–8.5% by weight, and the trace metals nickel and vanadium are lower than 2 parts per million (p.p.m.). The crudes give good yields of light and middle distillates but are unsuitable as a source of heating oils and bitumen. Gas contents are variable even between adjoining structures. Some are full of wet gas whereas others have oils that are undersaturated, and some reservoirs will therefore require supplementary energy so that the reserves can be recovered.

Estimating the reserves

Our estimates of proved reserves of oil are based largely on published information, including stated offtake plans and

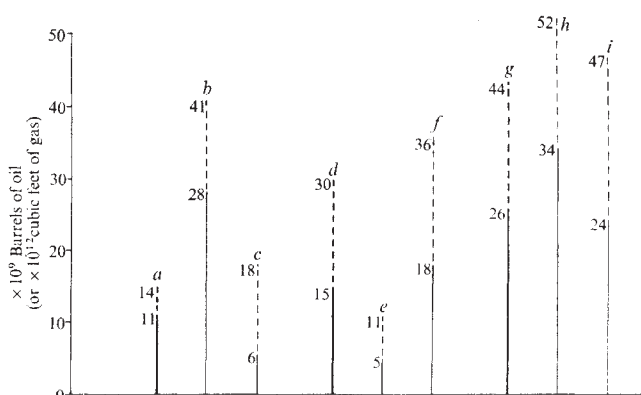


Fig. 3 Recoverable oil and gas reserves in the North Sea. *a-c*, Established reserves; *d-f*, additional reserves; *g-i*, potential ultimate reserves. *a*, Oil; *b* and *c*, non-associated gas, south and north respectively; *d*, oil and gas liquids, *e* and *f*, non-associated gas, south and north respectively; *g*, oil and gas liquids, *h* and *i*, non-associated gas, south and north respectively. Unbroken lines, reserves in UK waters; dashed lines, reserves in the remainder of the North Sea (in both cases: heavy lines, oil; fine lines, gas).

production potential, and they are supplemented from our own borehole and geophysical knowledge of the various structures. Table 1 lists the fields and discoveries, with estimates of recoverable reserves.

Of these discoveries only the main Ekofisk and Dan Fields are currently on production, but all of the named oilfields, with the possible exception of Josephine and Maureen, will probably be producing by some method by 1978. Supposing that the present commercial viability of discoveries depends upon sustained production capabilities of greater than 30,000 barrels of oil a day (or alternatively, 100 million cubic feet of gas a day), and considering that the discoveries of the northern North Sea have taken 100 exploration wells in the UK sector and 80 in the Norwegian sector, then the present success ratio is unusually high, at 1:6 (assuming that each of Ekofisk group of fields is a separate commercial discovery). It is probable that some of the wells were drilled only for stratigraphical information, and some may have been drilled with little

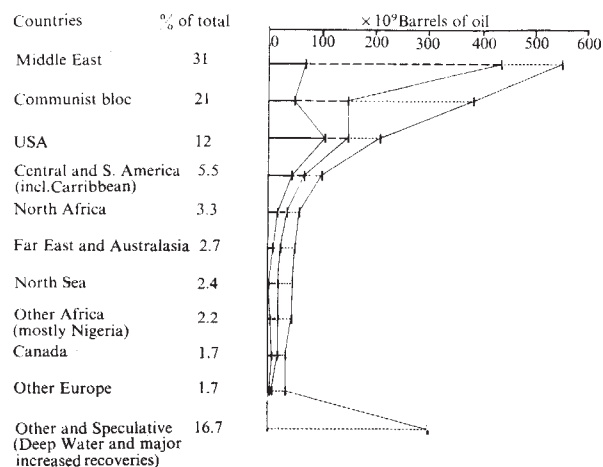


Fig. 4 World oil production, showing remaining reserves and possible future discoveries. Solid lines, produced reserves (300×10^9 barrels); dashed lines, remaining reserves (600×10^9 barrels); dotted lines, possible future discoveries (900×10^9 barrels). The potential ultimate reserves therefore total $1,500 \times 10^9$ barrels.

hope of success, only as a commitment to government for obtaining the licence. Some even, were probably drilled in the wrong place because of mistaken concepts of geology or geophysics. I assess that of some 220 prime prospects of present 'plays', about 85 have been explored. The proved reserves resulting from these tests in both Norwegian and UK sectors of the northern North Sea are >14 (for instance, 15×10^9 barrels of oil, 18×10^{12} cubic feet of unassociated gas, and >1 (for instance, 2×10^9 barrels of condensate (see Table 1 and Fig. 3). Using these statistics the ultimate reserves would seem to be 39×10^9 barrels of oil, 47×10^{12} cubic feet of unassociated gas, and 5×10^9 barrels of condensate (Fig. 3). Most of the major structures in the

North Sea Basin is about 94,000 cubic miles down to economic basement. Assuming that this is a category A basin, there would be an ultimate recovery of 42×10^9 barrels of petroleum liquids. The close similarity of this result with my figure of 44×10^9 barrels of petroleum liquids is comforting, although perhaps fortuitous, as both methods rely on very doubtful criteria.

Our calculations of world oil production, reserves, and future possibilities split into well defined regions, are illustrated in Fig. 4, based on the work of Warman⁸. Since his calculations, more oil has been produced, of course, and a little more has been discovered, but our estimates of future possibilities are slightly less. Now, of the grand total of

Table 1 Possible commercial discoveries in the North Sea

Country and block	Field	Estimate of recoverable reserves		
		Oil $\times 10^9$ barrels	Condensate $\times 10^9$ barrels	Gas $\times 10^{12}$ cu. ft.
Terhary 'play'				
Norway 7/11	Cod			
Norway 25/1 and UK10/1	Frigg			
UK 23/1	Lomond			
Norway 25/4	Heimdall		>1.0	>18.0
?UK 3/19	(Total <i>et al.</i>)			
Norway 25/2	(Petronord <i>et al.</i>)			
Norway 30/10-2	(Esso)			
UK 22/18	Montrose			
UK 21/10	Forties			
UK 16/28	Maureen	2.35		
Cretaceous 'play'				
Norway 2/4, 2/5 and 2/7*	Ekofisk Group	3.20		
Denmark	Dan			
Jurassic 'play'				
UK 211/29	Brent			
UK 9/13	Beryl			
UK 211/18	Thistle			
UK 211/26	Cormorant			
UK 15/17	Piper			
UK 211/23	Dunlin	>8.10		
UK 3/14a	Alwyn			
UK 211/28	Hutton			
UK 2/5	(Union <i>et al.</i>)			
UK 3/15	(Total <i>et al.</i>)			
UK 3/8 (and 3/3)	Ninian			
Norway 33/12	(Mobil <i>et al.</i>)			
Others				
UK 30/13	Josephine			
UK 30/16	Auk	0.35		
UK 30/24	Argyll			
Totals		>14.0	>1.0	>18.0

* Includes Ekofisk, Eldfisk, Torfelt, W. Ekofisk, SE Tor, Edda, and Albuskjell.

southern North Sea Basin have been examined, but remaining reserves there, although difficult to find, may amount to 11×10^{12} cubic feet of gas (Fig. 3).

Another, somewhat suspect method of reserves analysis, is based upon the volumes of basin sediment down to the economic basement. Weeks⁷ categorised offshore sedimentary basins out to a water depth of 1,000 feet according to favourability for petroleum resources by area. His category A basins totalled 188,000 miles², and the average basin thickness was 2 miles, giving a total volume of sediment of 376,000 miles³ in these basins. Weeks estimated that the A basins contained potential liquid petroleum reserves of 170×10^9 barrels recoverable by primary production methods, and, therefore, that average potential was 448,000 barrels a cubic mile. Similarly, his lower category B basins of 1,657,000 miles², have an average potential of 160,000 barrels a cubic mile. The volume of sediments in the northern

$1,800 \times 10^9$ ultimate barrels, 300×10^9 barrels have already been produced. We believe, therefore, that some $1,500 \times 10^9$ barrels could remain, of which 600×10^9 are proved reserves. Again, of the possible $1,500 \times 10^9$ barrels, about 800×10^9 barrels are the remaining and possible future reserves of the Middle East and Communist bloc countries. A further 300×10^9 barrels could come from reserves in continental shelf areas in waters deeper than 1,000 feet, or from speculative and unforeseen breakthroughs in, for instance, primary recovery processes. The rest of the world therefore seems to have remaining and possible future reserves of 400×10^9 barrels, of which 140×10^9 have been proved and 260×10^9 are possible. The North Sea, with established reserves of more than 15×10^9 barrels of petroleum liquids and about 30×10^9 potential barrels would seem to rank well with the rest of the world apart from the Middle East and Communist countries (10–11%).

Table 2 League table of oil producing countries in 1973^a

Country	Average production (millions of barrels a day)
USA	9.2
USSR	8.4
Saudi Arabia	7.6
Iran	5.9
Venezuela	3.4
Kuwait	3.0
Libya	2.2
Nigeria	2.1
Iraq	2.0
Canada	1.8
Abu Dhabi	1.3
Indonesia	1.3
Algeria	1.1
Others (less than 1 million barrels each a day)	6.2
Total	55.5

Future offtake patterns

Turning now to offtake potential to the end of the century, Fig. 5 shows what we believe could be the UK build-up pattern of yearly production, based on the proved reserves of 11×10^9 barrels of oil, and supplemented by the assessed additional reserves of 15×10^9 barrels still to be discovered. Superimposed is the Norwegian picture, built up from the 3×10^9 barrels of established reserves, supplemented by the assessed additional reserves. The patterns are built up from considerations of the time needed to prepare the facilities which are necessary for commercial production from particular fields after their discovery. Furthermore, in normal individual fields it is impractical and undesirable to

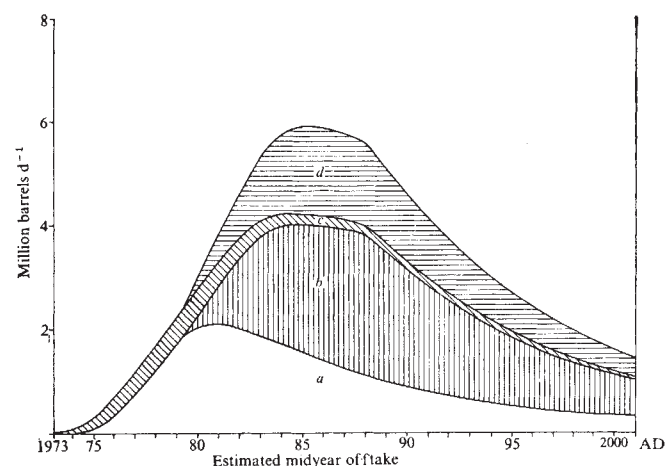


Fig. 5 Possible oil offtake pattern from the North Sea until 2000 AD. *a*, UK offtake of proven reserves; *b*, UK offtake assuming a maximum discovery rate; *c*, Norwegian offtake of proven reserves; *d*, Norwegian offtake assuming a maximum discovery rate.

produce at rates exceeding 10% of remaining reserves per annum. In most cases, if this rate is exceeded the ultimate recovery is decreased. It is, in fact, more realistic to anticipate a reserves production ratio not exceeding 15:1. The graphs of Fig. 5 take these factors into account in the total indicated for each year.

The present league table of individual producing countries, including the Middle East giants, is shown in Table 2, which has been derived from average figures for 1973 (ref. 9). Figure 5 shows that the UK will join this league before the

end of 1978, and should remain in it until 1988, even if no more oil is discovered. If our estimates of finding the postulated undiscovered reserves are correct, then we shall still be producing about 1 million barrels of oil a day at the turn of the century.

In addition to the amount of oil present in the ground, the offtake pattern also depends upon the will of governments and peoples to extract it. The rate of extraction depends upon the availability of material, financial and labour resources—steel and concrete platforms, drilling units, well completion systems, separators, pipelines laid in deep waters, treatment and storage facilities, and so on—which are necessary to get the oil to the user. The unit cost of development is now running at £1,200 a barrel/day potential and, if inflation continues at the present rate, could escalate at 10% per annum. If the not inconsiderable exploration costs are included, then by 1982 a total expenditure of some £13,000 million will have been necessary to finance the oil development of the North Sea alone if all other resources, and the will, are available¹⁰.

The possible developments on the western shores of the UK—Celtic Sea, Western Approaches, and west of the Shetlands, not to mention further out in the Atlantic, have not been considered here, so a little imagination is needed to increase the various parameters. Until a viable discovery is made I prefer to keep all options open. Reserves may be in proportion to those in the North Sea whereas, on the other hand, the various basins could be virtually empty of hydrocarbons, or contain only gas. Even using the suspect techniques of considering sedimentary volumes, however, the reserves do not seem very high. For instance, the W Shetlands basin out to a water depth of 1,000 feet contains about 13,000 miles³ of sediment, and if this is a Weeks' category A basin it would contain 5.8×10^9 barrels of petroleum liquids. On the other hand, if it is a Weeks' category B basin it would contain only 2×10^9 barrels. Similarly, the Celtic Sea with about 9,800 miles³ of sediment could contain 4.4×10^9 or 1.6×10^9 barrels, respectively. Even these theoretical and probably optimistic amounts do not significantly affect world statistics, and only increase my guess at the ultimate reserves of the UK sector by 14–40%. They are included in the category Other Europe in Fig. 4.

In painting this rosy picture of imminent oil availability to the UK, in these days of awareness of a possible world energy shortage, I do not wish to create a complacent and parochial attitude of "I'm all right Jack". I believe that the fortunate accident of nature that has provided these resources on the doorstep of the UK, also provides an opportunity to study and resolve the problems of longer term energy requirements. Nevertheless, even with good husbandry and no increase in requirements, the reserves I have postulated are finite and will have been substantially depleted by the turn of the century.

I should like to thank the Chairman and Board of Directors of British Petroleum for permission to publish this article.

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Huge resources needed to exploit shale oil

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Although there is plenty of shale oil in the United States, treatment at the surface of the rock that contains the oil would require prohibitive amounts of water. But the alternative, production in situ, is not yet a well developed technique.

EARLY this year two oil companies together bid \$210 million to lease from the federal government 5,000 acres of arid land in the remote north-west corner of Colorado. At that price, the land is almost as expensive as a prime piece of suburban real estate, and when the bid was announced it surprised not only much of the oil industry but also some of the government officials responsible for leasing it.

The reason why this rugged, largely unspoiled, part of the Rocky Mountains has suddenly become a boom area is simple: it contains more oil than the Middle East. The oil is locked into a band of rock, popularly known as oil shale, which varies from a few feet to about half-a-mile in thickness. According to the United States Department of the Interior, a region of 25,000 square miles which straddles the borders of Colorado, Wyoming and Utah contains about 1.8×10^{12} barrels of shale oil, about a third of which is in deposits rich enough to be exploited.

Already, the promise of this vast petroleum reserve has sparked off gold-rush fever in the small ranch towns in the area—motels are filled to bursting and the population is booming. The federal government, which owns more than 70% of the richest shale lands, is being pressed to speed up its commercial exploitation, and several newspapers—including the *London Times*—have suggested that Rocky Mountain oil shale could be the answer to the energy crisis, not only for the United States but for western Europe as well.

Unfortunately, however, such predictions are grossly over-optimistic, for there are several reasons why the Rocky Mountains will never upstage the Middle East in the international crude oil market, and in any case it will be a long time before shale oil starts flowing through pipelines and heating furnaces. Nevertheless, there is no doubt that shale oil could eventually supply a significant amount of the energy demand of the United States, and there is also no doubt that shale oil production will be accompanied by massive destruction of the environment.

The lease sale this January, which brought the staggering \$210 million bid, was the first tentative step in a programme designed to test whether or not the shale fields should be thrown open for commercial development. A total of six such tracts of land have now been put up for lease to private industry—two each in Colorado, Wyoming and Utah—to test various methods of getting shale oil out of the rocks and to give the federal government an opportunity to see what environmental consequences are likely to result from complete commercial exploitation of the shale fields. If the tests prove successful, and if the environmental consequences are deemed 'acceptable', the Department of the Interior, which manages the lands, reckons that up to 1 million barrels of shale oil a day could be flowing out of the Rockies by 1985.

Although that amount is not to be sniffed at, it will represent less than 5% of anticipated demand in 1985 and according to several recent studies it could be close to the physical limit of production capability. The test operations being carried out both on the leased federal lands and on some private land will probably determine the likely potential for oil shale, but much will also depend on the extent to which the federal government becomes involved in the enterprise.

Deposits and extraction

It has long been known that massive deposits of oil are contained in the sedimentary rocks of an area known as the Green River Formation, and in fact some oil was produced from shale even before liquid petroleum was discovered in 1859. But in spite of about thirty years of research and development by the oil industry and the federal government, it has been uneconomic to produce shale oil on a commercial scale for the simple reason that the cost of extracting it from the rocks meant that shale oil could not compete economically with natural petroleum. But the economics were suddenly altered when the price of crude oil began to skyrocket and the Nixon Administration launched its pell-mell drive to make the United States self sufficient in energy.

Shale oil is locked into rock in the form of a solid hydrocarbon called kerogen. To get it out requires the rock to be heated to about 900° F (480° C) and the vapours that boil off to be collected. The result is a viscous, low gravity, moderate sulphur and high nitrogen crude oil which will probably have to be 'upgraded', partially refined, before it is piped to refineries.

Two different approaches to getting oil out of the sedimentary rocks of the Green River Formation have been tested so far, albeit on a modest scale. One approach involves mining the oil-bearing rocks, crushing them and heating them in a surface retort, and the other involves mining or blasting out an underground cavern and heating the shale in place by burning gases. The former method has been more extensively tested, and is reckoned to be closer to commercial application, but the second method, the *in situ* approach, could have significant advantages if it proves feasible on a large scale.

Three chief types of surface retort have been tested, all of which have been operated at the level of 1,000 tons of rock a day. Of these, it is reckoned that a design piloted by the Oil Shale Corporation (TOSCO) is closest to commercial application, but all of them could be scaled up to production levels over the next few years, according to a report prepared recently by the Atomic Energy Commission (AEC) for the Federal Energy Office.

The TOSCO process has as its central feature a rotary kiln into which is fed preheated shale crushed into pieces less than 0.5 inch in diameter. Retorting is carried out by means of externally heated ceramic balls, which are later separated from the spent shale and reheated. The products are drawn off and filtered. According to TOSCO, the process produces an excellent yield, a claim supported by the AEC study, and there should be little trouble in scaling it up to commercial production.

Another process being actively pursued by a number of oil companies is the so-called gas combustion method. This makes use of a vertical retort through which crushed shale moves downwards and gases, fed in at the bottom, move upwards. Air and some additional recycled gases are fed into the retort at a point about one-third of the way from the bottom, which causes the gases to burn. This retorts the shale, and oil vapours and gases, cooled by the incoming shale, emerge from the top. According to the Department of the Interior, "of the numerous retorts studied in the Bureau of Mines program, the gas combustion retort gave the most promising results". Seventeen major oil companies have recently begun to test a modification of the gas combustion process, and according to the AEC study, it will be about three years before the process reaches the stage that the TOSCO process has reached now.

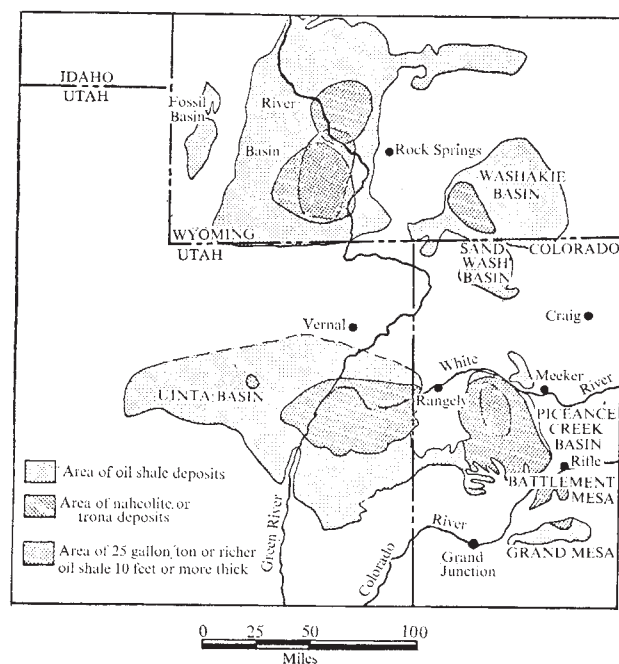


Fig. 1 Oil shale areas in Colorado, Utah and Wyoming.

The third method, the Union Oil Company process, also uses a vertical retort with a countercurrent flow of shale and gas, but in this case the shale is fed in through the bottom. Air is pumped in at the top of the retort and heat is supplied by the combustion of carbonaceous residue which remains on the spent shale. The process was tested in 1957 and 1958 on private land in Colorado, and Union Oil recently announced that it is planning to construct a 50,000-barrel-a-day plant which could go into operation by 1979.

Although the retorts are the only pieces of new technology used in the surface processing of oil shale, the scale of commercial operations will probably be limited by other factors, chief of which is the massive amount of mining that will be required to support even a 1-million-barrel-a-day enterprise.

The shale will be mined either by open pit methods (when it lies close to the surface) or by the room-and-pillar method, but whichever is employed a simple calculation indicates that it would have to be on a truly staggering scale. Assuming that the shale used in the surface retorts contains 30 gallons of oil per ton (one US barrel is 42 gallons), to extract 1 million barrels of shale oil a day with a recovery rate close to 100% would require the mining of about 1.6 million tons of rock. That is an enterprise similar in scale to the entire United States coal industry.

Environmental problems

A direct consequence of this massive mining operation is that there will be an equally massive amount of processed shale to dispose of once the oil has been removed. Since the crushing and retorting operation greatly expands the shale, the spent material cannot be simply fed back into the mines, and so it will be dumped into canyons (and revegetated?).

The spent shale will be bone dry and very dusty, and consequently it will not be easy to get rid of it. It is this aspect of the oil shale operations which most troubles environmental groups, and before the Department of the Interior decides to throw the entire region open to commercial development, it will have to be certain that the spent shale can be dumped and revegetated without undue environmental disruption, however that may be defined.

A second, and ultimately more intractable problem for a large oil shale industry, is the shortage of water in the Green River Formation. According to an environmental impact statement published by the Department of the Interior in August, 1973, a 1-million-barrel-a-day operation would require between 107,000 and 170,000 acre feet of water a year, and municipal development associated with industrialisation of the area would require another 14,000–19,000 acre feet of water. The impact statement suggests that about 340,000 acre feet of water is potentially available for oil shale operations.

This clearly does not give much room for manoeuvre and the AEC study flatly states that "the ultimate rate of production of an oil shale industry may be limited by the amount of water available, although the competition for water should not be severe for a 1-million-barrel-per-day industry". The study adds "a 3 to 5 million-barrel-per-day industry could possibly be established if all the water in the oil shale regions of Colorado, Utah and Wyoming were made available for oil shale development". That would mean, however, that agriculture, minerals processing and other energy industries such as the production of coal gas would have to be severely curtailed.

The chief consumers of water in the oil shale production process are the disposal of spent shale and the upgrading of shale oil so that it can be transported by pipeline. According to the Department of the Interior's impact statement, those two processes between them would use up about half of the water consumed in oil shale production.

Thus if water consumption and mining requirements can be reduced, the potential for oil shale production would be greatly expanded. And that is precisely why the *in situ* process is now being looked at very carefully.

Processing *in situ*

The first thing to be said is that *in situ* technology is not as advanced as surface processing technology, and in spite of some extraordinary claims made by companies involved in *in situ* research and development, there are many problems to be overcome before it can safely be assumed that the technology is ripe for commercialisation.

Nevertheless, one company in particular, Occidental Petroleum and its research arm, Garrett Research and Development Company Inc., has recently carried out a test of an *in situ* process which seems promising. According to Mr Richard D. Ridley, Garrett's manager of oil shale research, the process works like this. First, a room is mined out of the rock beneath and/or above the oil shale. The rock is brought to the surface, where it is either retorted in the conventional manner if it is rich enough in oil shale, or simply dumped and revegetated. The next step is to load explosive charges into deep holes drilled into the walls of the excavated rooms and fire them off so that as the oil shale breaks it will fill the room with tightly packed oil shale rubble.

The final stage is to retort the oil shale in place. This is accomplished by drilling a hole into the top and bottom of the rubble-filled cavern and circulating air through it. Initially, combustion is caused by pumping in natural gas, but eventually carbon left on the shale after it has been retorted provides the fuel. Shale oil runs into a sump at the bottom of the cavern, and it is eventually pumped to the surface.

Occidental has already tested its process on private land in Colorado and it will be conducting a larger test later this year. According to Ridley, if that test is successful, Occidental will be ready to move into commercial production. There are a few problems, however. For one thing, it has been suggested that the *in situ* process will cause subsidence, a criticism which Ridley flatly denies but which has been made by knowledgeable oil industry experts in testimony before the House Science and Astronautics Committee. Another problem is that some of the oil shale is overlain by an aquifer which must be kept isolated from the underground retorting process. Again, Ridley claims that this will be no problem but other oil industry officials are not so optimistic.

Speed of exploitation

One indication of the fact that most of the oil industry is not ready to move into *in situ* processing is that of the six tracts of land put up for lease by the federal government, the two which are suitable for *in situ* methods failed even to attract a single bid. The Department of the Interior is

now wondering whether to offer them for sale again, but in any case the lack of interest in the two tracts has already led to calls for increased government support for the development of *in situ* technology.

Strong arguments are in fact being raised for the federal government to speed up the exploitation of all the shale lands by immediately leasing more federal land than the six prototype tracts and by providing a variety of financial incentives to the oil industry, such as loans, price guarantees or tax breaks. Moreover, a bill has already been passed by the Senate which would, among other things, establish a joint government-industry corporation to build demonstration oil shale plants; a similar measure is now under discussion in the House of Representatives.

The AEC study recommends that since the potential for *in situ* plants is so high and since the technology is at present not very well advanced, the federal government should concentrate its efforts in this area by assisting industry to establish a plant capable of producing 30,000 to 50,000 barrels of oil a day, to demonstrate the technology on a commercial scale. "If construction began in mid-1975 such a plant could be in operation by mid-1977 and, if successful, could lead to an industry production capability of about 1.8 million barrels per day by 1985," the report says. And the AEC study also suggests that although there is every indication that industry will move by itself to establish commercial-scale surface processing plant, "there are no assurances that significant production by 1980 will result without a major role being played by the government".

Japan and the energy crisis

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The central problem facing Japan is how to reduce her growing reliance on imported oil.

For many years Japan had a plentiful supply of energy because of her extensive water resources and domestic coal. Towards the end of the 1950s, however, the import of petroleum (a relatively cheap commodity at that time, supplied mainly by countries in the Middle East) increased rapidly to meet the needs of industrial growth. The way in which the proportions of primary energy supplied by various means have changed over the years is shown in Table 1.

Petroleum replaced coal as the chief source of energy in the early 1960s and Japan entered the 'oil era.' Until the recent oil crisis, there was no difficulty in importing cheap oil from abroad and Japan's long coastline, with many good harbours, helped to keep the price relatively low.

The problem in Japan as regards energy supply thus has three major aspects. First, the dependence on oil imports has become so high that the supply is unstable and easily affected by the political and economic situations outside Japan. This is made even worse because more than 90% of the imports came from one region of the world.

Second, the absolute amount of petroleum consumed has become so high that Japan is consuming about 10% of that available to the whole world in spite of the fact that its population is less than 3% of the world total. There is no assurance that Japan will be able to maintain such a large share in the future.

Japan has an area of only about 400,000 km², about 4% that of the United States, and is consuming about one-third of

the energy being consumed in the United States. That means that the density of energy (per unit area) is about nine times that of the United States; it also means that the degree of air pollution may be some ten times as great if the measures for preventing pollution are the same.

Japan was faced with a shortage of oil immediately after the declaration of an oil embargo by the Arab countries. Fortunately, the shortage was not too serious as regards quantities but it caused a sharp rise in the cost of oil, which is making itself felt in the cost of all energy sources. The electric power utilities, for example, are proposing to raise the price to the consumer by about 60% on average, which will have serious effects on the whole economy.

Thus Japan has been forced to reconsider the whole system of energy supply, taking the problems mentioned above into account. The first problem to be faced is the saving and the

Table 1 Supply of primary energy in Japan

	1955	1960	1965	1970	1975 (estimated)
Hydroelectric power (%)	21.5	15.3	11.3	8.3	6.6
Coal (%)	49.2	41.5	27.3	21.4	16.3
Petroleum (%)	20.2	37.7	58.4	67.2	72.8
Nuclear power (%)	0	0	0	0.6	2.4
Dependence on imports (%)	24.1	44.3	66.2	76.4	82.4
Total energy* (10 ¹¹ kl)	5,125	8,438	14,576	33,100	44,700
Ratio	1	1.65	2.84	6.46	8.72

* Petroleum equivalent, 10,000 kcalorie l⁻¹.

effective use of conventional energy. In considering the measures needed, a detailed analysis of the structure of the consumption of energy in the country has to be made. Tables 2 and 3 show the general structure estimated by the Ministry of International Trade and Industry (MITI) as of 1972.

Details of the measures for saving energy and using it effectively are being developed in industry and research institutions with the support of the government.

The second problem in overcoming the shortage and unstable supply of energy is the utilisation of domestic coal. The coal reserves in Japan are estimated to be about 20×10^9 tons. In the early 1950s, annual production reached 50 million tons a year but the increasing importation of cheap oil has meant that coal production has decreased gradually to the present rate of only 20 million tons a year.

Increasing the use of coal raises two difficulties. First, a huge investment will be necessary to increase the annual production again. The importation of coal is a possibility, but transportation and the requirement of a stable supply may cause problems. The second difficulty is air pollution. As a means of avoiding this, the gasification or liquefaction of coal are being studied. Both are still in the stage of basic research, and the government has started a development programme this year.

The third measure is the exploitation of new energy resources. Leaving aside nuclear energy, which is discussed later, development of various new resources is included in various government projects. There are many active volcanoes in Japan, for example, so there is plenty of potential geothermal energy.

Table 2 Structure of the demand for energy (%)

	Petroleum	Electricity	Others	Total
Manufacturing industries	32.11	15.33	17.41	64.85
Transportation	11.64	0.81	0.95	13.40
Home use	7.96	7.51	3.56	19.03
Others	—	—	—	2.72
Total	52.47	25.13	22.40	100.00

The development of this source of energy has a long history, but because of economic and technical difficulties, only two electricity generating stations are in operation: they have a total capacity of about 30 MW. In order to proceed any further, much developmental study is necessary, for example on deep well technology.

The government has also taken up the use of solar energy as its next energy project. Assuming that 1% of the solar energy falling on Japan is used at an efficiency of 10%, solar energy could provide the wherewithal to generate about 40 million kW of electricity. In Japan there are 2.5 million sets of solar water heating units installed in homes—equivalent to a few hundred thousand kW of electrical heaters. In combination with city gas or electricity, these units may be developed to more efficient devices for home heating and cooling. Other devices such as solar batteries and solar heaters for generating steam are also being examined.

One of the most important aspects of energy in the future is the protection of the environment. To this end, the use of hydrogen as a carrier of energy is under study as well as other means of obtaining clean energy, such as the removal of sulphur and nitrogen oxides from the exhaust gases arising from the combustion of petroleum and other fuels.

The work on the development of solar and geothermal energy, utilisation of coal and the use of hydrogen are all being carried out as part of a project called "Sunshine" which is a government-supported five-year programme. It has just been started and the budget for the fiscal year 1974 is about 2.3×10^9 yen (about \$7 million).

Except for solar energy, however, there is a limit to the amount of energy available in each category and it is not high enough to meet the future needs of Japan. The snag with solar

energy is that it will be a long time before it can be used in large quantities.

The deduction from all this is that nuclear energy is the only effective substitute for petroleum that is likely to be available this century. In Japan, the current installed capacity of nuclear power plant is some 1,750 MW, and some 15,000 MW more is under construction.

Recently, Mr S. Inaba, a Commissioner of the Japanese Atomic Energy Commission, estimated the structure of energy supply up to 1985 (see Table 4). The data given there do not reflect any official decision, but are estimated by Commissioner Inaba on various assumptions such as stable growth of the economy, the possible development of each category of energy and so on. The energy development programme is under discussion in various government departments and the long term plan for the programme is expected to be formulated this year. In any event, it is considered that nuclear energy will have a key part to play in the future Japanese energy scene.

Table 3 Demand for petroleum classified by end use as of 1971

	%		
Power	17.8		Mainly transportation
Heat	66.1	28.4	Industries
		22.3	Electric power generation
		15.4	Home use and so on
Material	12.8		
Others	3.3		
Total	100.0		

In developing nuclear power, however, there are many serious matters to be considered which are peculiar to Japan. Safety regulations for nuclear plants are very strict because of the high population density and the necessity for designing equipment that is resistant to earthquakes. Radioactivity pollution is a serious hazard especially because of the active off-shore fisheries. There are no parts of the coasts of Japan that are not concerned with fishing industries. It is also difficult to find suitable locations for fuel reprocessing and waste disposal.

Table 4 Estimated future structure of the energy supply in Japan

	1972 (Actual)	1975	1980	1985
Total supply	366	447	603	800
(Petroleum equivalent, 10^6 kl)				
Annual increase (%)	10.7	6.3	6.2	5.8
Petroleum (10^6 kl)	258	301	393	497
% of total supply	75	72	69	66
Coal (% of total supply)	17	17	15	13
Hydroelectric (% of total supply)	6	5	4	3
Nuclear power (10^6 kW)	1.8	7.4	28	60
Generated energy (kW h)	9.5	49	184	394
% of total supply	1	3	8	13
Others (% of supply)	1	3	4	5

As with other natural resources, Japan is short of indigenous uranium. Therefore, she has to develop nuclear power plants which use uranium as economically as possible. Accordingly, a demonstration power reactor of the heavy water type (165 MWe capacity) is under construction. There is also a fast breeder reactor programme. A liquid metal cooled experimental breeder reactor (50 MW thermal) is under construction and a demonstration fast breeder reactor (300 MWe) is being designed.

Japan has a large ship building industry which is interested in a future programme involving nuclear ships. A nuclear cargo ship of about 8,000 tonnes and with a nuclear reactor of 36 MW thermal has been completed and is awaiting sea trials.

Nuclear fusion is a promising field in the long term. In Japan, research has long been concerned with the basic side, that is, the

study of plasma. Recently, the research has become oriented towards the practical realisation of fusion and more resources are being allocated to it.

The present budget of the government for all the nuclear

projects, including fusion, is about 67×10^9 yen (about \$230 million) and it is estimated that industry is spending about the same amount of money. About 15% of the governmental budget is devoted to programmes of safety research and development.

Europe in turmoil finds time to discuss energy

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Compared with the United States, which imports only a few per cent of its total energy needs, and the Soviet Union, which is a net exporter of energy, Europe is heavily dependent on outside supplies.

IN Europe the nine countries of the economic community are in the process of piecing together an energy policy. Briefly, the plan calls for a reversal of Europe's energy supply position. Instead of 60% of Europe's needs coming from outside and 40% from indigenous sources as at present, the plan says that by 1985 only 40% should be imported and 60% originate within the community.

The reasoning is that the Nine will then have a greater measure of control over the energy received from outside and the price they have to pay, although clearly Europe will continue to be at the mercy of outside suppliers to a considerable extent.

In some ways it is back to the early 1950s when fears of a shortage of energy were instrumental in the establishment of the European Coal and Steel Community and of the ill-fated Euratom organisation. Now after two decades when energy has been plentiful and cheap, energy problems once again loom large in the European communities.

At present there is no ready-made framework for considering energy questions. There has been no common energy policy in the way that there is a common agricultural policy. A good thing some would say (although it is now being argued that the common agricultural policy has not been so inflationary for Britain as was at first feared) but the lack of an energy policy has meant that when a crisis strikes the European countries have no guidelines for action.

In fact each of the three communities in Europe has a finger in the pie. Euratom looks after nuclear energy, coal comes under the European Coal and Steel Community, and the European Economic Community itself (the EEC) deals with oil. The same goes for energy research. Euratom is looking into alternative forms of energy—the so-called hydrogen economy for example—as well as doing nuclear research, the Coal and Steel Community is supporting coal research and the EEC spends money on research into the development of oil.

Apart from the reduction in Europe's reliance on imported energy, the keystones of the proposed plan which was formulated by the European Commission are that oil should in future be regarded less as a fuel for burning and more as a raw material for the chemical industry, and that by 1985 the nine member countries' appetite for energy should be 10% below the present estimates for 1985 consumption, this saving to be brought about by using energy more sensibly than before.

Future mix

The planned distribution of sources of energy is shown in Table 1, with the present distribution for comparison. Taking the energy sources one by one down the table:

- **Coal.** Production within the EEC is to remain virtually steady—179 million tonnes (Mt) of oil equivalent in 1973 and 180 Mt in 1985. There will, however, be a reduction in output from the spent mines of north-east France, Belgium and Holland which will have to be matched by increased exploitation of the British and German coal-fields. The rise in the consumption of solid fuel indicated in Table 1 will come from an increase in the utilisation of peat and peat coal mainly from Germany (25 Mt oil equivalent to 40 Mt) and a big increase in coal imports (21 Mt oil equivalent to 35 Mt).

- **Oil.** The main factor here is that the reserves in the North Sea should increase community oil production from a paltry 11 Mt in 1973 to 180 Mt in 1985, with a corresponding drop in imports if the demand for oil can indeed be kept down as shown in Table 1. The burning of oil in power stations and in central heating systems is to be discouraged, but it will have to continue to be burnt in cases where there is no foreseeable substitute—notably in road transport and aviation.

- **Hydraulic and geothermal energy.** The commission believes that there is not much scope for increasing the use of these sources in the community, so they will continue to play only a small part in the energy budget.

- **Natural gas.** An increase in exploitation of the gas beneath Holland and the North Sea will increase internal European production from 113 Mt oil equivalent to 225 Mt in 1985. Even so, imports will also jump from 4 to 150 Mt.

- **Nuclear energy.** A big leap forward in use is envisaged. This may not please the most extreme of the environmentalists.

Taken together these figures mean that energy imports to the Nine will slightly increase from 553 Mt oil equivalent in 1973 to 580 Mt in 1985, while the supply from indigenous sources will go from 369 Mt to 920 Mt, making Europe proportionally less dependent on external factors, but still requiring a considerable input of energy from outside.

At a New York conference on energy supplies, organised by the *Financial Times* and *Oil Daily*, the Director-General for Energy in the European Commission, M. Fernand Spaak, spelt out some implications of the plan: "This strategy requires the community to adopt and to implement a real supply policy for each source of energy within an overall energy supply strategy. Therefore the commission proposes a wide-ranging redefinition of the relationships between the public authorities and the energy industry, in particular those concerned with the transport, refining and distribution of oil and oil products. The objective is to

Table 1 European energy sources for 1985 compared with 1973 (figures in millions of tonnes of oil equivalent)

	1973		1985	
	Mt	%	Mt	%
Solid fuel	225	24.4	255	17
Petroleum	539	58.5	575	38.5
Hydraulic and geothermal	27	2.9	35	2
Natural gas	117	12.7	375	25
Nuclear	14	1.5	260	17.5
Totals	922	100	1,500	100

establish a code of conduct for the industry. The public authorities will monitor the industry's behaviour and will have the means of intervention when necessary".

Savings

The plan also envisages that high prices and a more rational use of energy will lead to a reduction in the annual growth rate of energy consumption by the Nine. Instead of an annual growth rate of 5.1%, predicted last year for the interval 1972-85, the aim is a growth rate of 4%. This makes the Nine's requirements for 1985 to be 1,500 Mt of oil equivalent, the figure used in Table 1, rather than the 1,660 Mt as estimated last year.

It is stressed in Brussels that this reduction does not mean that Europeans are going to go cold in the next ten years. Rather the commission says that by a more rational use of energy it means a reduction of energy input for the same level of output of useful energy. Table 2 shows the hoped-for pattern of consumption in 1985, leading to a total of 1,500 Mt of oil equivalent, compared with consumption if the higher growth rate continues. Figures for 1973 are given for comparison.

Table 2 shows that the European Commission has its eye on the improvement of the design of private dwellings. It

watch over the security of supplies to Europe by developing existing sources and prospecting for new ones, as well as doing some stockpiling. But the history of the nearest thing Europe has so far had to an energy agency—Euratom—is not a good omen.

So far the plan has been well received. All the same the people in Brussels responsible for formulating it are not counting their chickens before they are hatched. Anything can happen, they say, while Europe is in its present state of shock. The most important precipitating factor has been the British wish to renegotiate its terms of entry into the EEC. With the minority Labour government which is calling for the renegotiation still looking surprisingly strong, this question seems likely to hang fire for many months. Then there is the nature of the joint European relationship with its protector, the United States, to be resolved. Furthermore, this spring there have been unstable political situations in more European countries than is usual at any one time.

Prospects

These factors are undermining confidence in Brussels, where there is apprehension that the energy policy will not be judged on its own merits or demerits and that it may become a pawn in some completely unrelated political squabble, as happened last year when Britain, then with a Conservative government, refused to talk about energy (the question then being the formulation of a joint, short term, way of dealing with the shortages brought about by

Table 2 Energy consumption in 1973 and 1985 (figures in million tonnes of oil equivalent)

	1973	1985 (assuming abundant energy and low prices)	1985 (assuming a more rational use of energy)	Difference
Industry	483	900	850	-5%
Transport	119	215	180	-15%
Private dwellings and so on	317	545	470	-15%
Totals	919	1,660	1,500	-10%



Fig. 1 Mr Fernand Spaak (left): a wide ranging redefinition of the relationships between the public authorities and the energy industry. Mr Henri Simonet (right), Europe's Commissioner for Energy.

has been fashionable for years to say that the thermal design of many houses leaves a lot to be desired, but next to nothing has been done about it.

In the transport sector the savings are to come from increasing the efficiency of existing means of transport and, more vaguely, by better town planning. In industry the commission is hoping for more efficient combustion of fuels and the utilisation of heat that would otherwise go to waste, coupled with a trend towards continuous processes and an end to the planned obsolescence of products.

Finally the plan calls for a European Energy Agency to

the Arab oil embargo) until Britain got more out of the EEC regional fund.

But so far the talks have gone well—perhaps unexpectedly well. During April the Commissioner for Energy, M. Henri Simonet, presented the plan to the Energy Committee, composed of the senior officials responsible for energy in each of the member states. The committee quickly gave its broad approval (which means that the Conservative line in refusing to talk about energy is not being followed by Labour), but there has been some quibbling about details.

The French and Germans are worried about the problem of marketing the coal once it has been mined if there is a deterioration in its price competitiveness, and the community may have to give aid to coal-mining in exchange for the security of supply endowed by coal.

The British, with their memories of the recent miners' strike and Mr Patrick Jenkins' exhortation that they should clean their teeth in the dark, pointed out that a lot of effort will have to be put into negotiations with the trades unions about rationalisation and wage policy British

coal mining may not be able to fill the gap left by the closure of the continental mines. And doubts that the increase in production of European natural gas hoped for by the commission could really be achieved were voiced by the Dutch.

A more serious difference of opinion has blown up over the extent to which the activities of the oil companies should be monitored and even, on occasion, interfered with during the implementation of the strategy, as indicated in M. Spaak's speech. France, Italy and Belgium seem to be

in favour of a greater degree of monitoring than at present and of the principle of more forceful governmental or community intervention, whereas Britain, Holland and Germany are supporting the oil companies' liberty, in particular with regard to the companies' pricing policies.

The Energy Committee seems, however, to be unanimous in desiring that the plan to be put to a meeting of the Council of Ministers as soon as possible. With Europe still at loggerheads over other important issues what may happen then is anybody's guess.

Energy problems facing India

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If India is to avoid the worst effects of the increases in the price of oil she must make better use of her indigenous sources of energy.

INDIA was experiencing acute shortages of energy even before the first of the increases in oil prices had set the stage for a worldwide crisis. These shortages had to do mainly with gaps between demand and supply of coal and electricity, the former aggravated by neglect through increasing dependence on imported petroleum products and the latter by two successive seasons of deficient rains.

Higher oil prices added to India's economic woes (through adverse effects on the balance of payments position) at a time when she was trying to cope with inflation, runaway prices, and sizeable shortfalls in industrial and agricultural production arising from the failure of rains during 1971-72 and 1972-73, and consequent curtailments in power generation (hydroelectric) and imposed cuts in its supply.

A look into India's industrialisation programme (in regard to the technologies employed, the materials used as inputs, the pattern of production and so on) would reveal only a nominal or incidental relationship with the resources available in the country, or the overall needs and interests of the nation or her people as a whole. The tying of agricultural development programmes to the increasing use of oil-based inorganic fertilisers, instead of organic ones, is another case in point.

In general, one is struck by the poor correlation between Indian resources and actual sources in key areas. The area of energy is no exception.

Sources and resources of energy

India gets her 'go' from both commercial and noncommercial (traditional) sources of energy. In the former category are: coal, oil, gas and electricity; in the latter dung, firewood and vegetable wastes.

The present consumption pattern, as far as commercial sources of energy are concerned is: 50% oil (including natural gas), 29% coal and 21% electricity. Electric power generation at the end of 1972-73 was 61% thermal (coal, oil), 37% hydroelectric and 2% atomic (enriched uranium). Similar figures for traditional sources are difficult to arrive at and unavailable. But very rough estimates of 1962-63 figures were made by the first-ever Energy Survey Committee in 1965. They may still be indicative of the relative importance of various traditional sources (Table 1).

Of the noncommercial sources dung is still estimated to be providing nearly 50% of all cooking heat used in the country.

India's resource picture with respect to various sources of energy is as follows:

Coal. It is fairly abundant (except for metallurgical varieties).

Known reserves (all types including lignite) are estimated at 83,000 to 100,000 Mt. Present annual demand and production (1973) are 95 and 79 Mt respectively.

Oil. Mineral oil is relatively scarce. The annual production of 7.5 Mt compared to the refinery consumption of 21.0 Mt in 1973 necessitated imports of 16 Mt (including petroleum products).

Electricity. (a) The potential for hydroelectric generation is abundant and has been estimated at 215×10^9 kW h energy a year. Of this, nearly 17% will have been harnessed when schemes underway are commissioned. Major problems are: uncertainties about rainfalls, high capital outlays, and long gestation periods required for completion. (b) The potential for thermal generation is great considering India's abundant coal reserves, provided she can increase its production. Gigantic thermal plants (near coal mines) of capacity up to 2,000 MW could feed a national grid to take power where needed. (c) At present usable nuclear fuel—natural uranium—deposits are very limited. Enrichment of uranium is not yet carried out in the country so fuel for India's only working nuclear power

Table 1 India's energy consumption (1962-63)

Commercial fuels			Noncommercial fuels		
Coal	Oil	Hydroelectric power	Dung	Firewood	Vegetable wastes
59.6	8.5	11.8	54.9	101.6	31.1
Mt	Mt	TW h	Mt	Mt	Mt
64.9	55.3	10.4	22.0	96.5	22.5
Mt c.e.	Mt c.e.	Mt c.e.	Mt c.e.	Mt c.e.	Mt c.e.

Mt, million tonnes; TW h, 10^9 kW h; lower figures are coal replacement equivalents for upper figures (Mt c.e., million tonnes coal equivalent).

station at Tarapur in Maharashtra has to be imported. India's thorium deposits are among the largest in the world, but breeder reactor technology which is essential for turning available thorium into fissionable fuel, has not yet been developed.

Cattle dung. This is quite abundant. India has the largest cattle population in the world and milche cattle alone number 67 million.

Wood and vegetable wastes. It is difficult to estimate the extent of consumption of wood and its replacement in the country. But it is feared that poor sections of the rural population, searching for free fuel, may be indiscriminately denuding the landscape at a rate faster than it is being replaced. This needs urgent attention.

Alcohol. It can be obtained in fair amounts through the fermentation of molasses—a by-product of India's sugar industry (among the world's largest). By itself, or mixed with petrol, it could run internal combustion engines in cars and

other vehicles. Actually, that is exactly what was being done in the country in 1947-48 and 1961-62. Agricultural pumpsets can also be run on alcohol with only slight modification to their engines.

Genesis of problems

Most of India's present energy problems are of her own making. The oil crisis which is at the moment threatening to jeopardise the country's entire development effort through its economic consequences is no exception. The problems primarily relate to commercial sources of energy—oil, coal, and electricity.

In less than a decade, starting with the early 1960s, oil has been allowed to push coal into the background and become the energy base of India's economy. This is in spite of the fact that India is known to be richly endowed with coal but quite poor as regards oil.

The emergence over a decade of the present oil-heavy pattern of energy consumption can be traced to untenable assumptions, bad planning and erroneous policies. But it may have been egged on by a number of factors: relatively easy and plentiful availability of oil at favourable prices, until recently; growth of a pattern of production suited to elitist consumption based on imported technologies heavily weighted in favour of oil as a source of energy; characteristic Indian exercise of 'soft options' in importing and implanting as a whole (by not bothering even to effect modifications in imported technologies to the extent of making them suit Indian needs or conditions and reducing or eliminating their continued dependence on imported inputs), and so on.

All this happened despite warnings issued by the first Energy Survey Committee, as far back as 1965, against 'accepting or encouraging, the shift towards oil without adequate caution or consideration.

A 'gobar-gas' (gobar for dung) plant, was devised by the Indian Agricultural Research Institute (IARI) as far back as 1959. The plant can take in all forms of animal excreta and even human night soil. Septic tanks too could support such gas plants. Between 1961 and 1973 only 7,500 such plants were installed, but 20,000 more will be installed in 1974-75 according to a recent government decision.

India's entire rural and agricultural energy demand can be met through installation of such plants throughout the countryside. Along with the gas, organic manure obtained from residual slurry can be used in conjunction with our indigenous output of chemical fertilisers to increase agricultural production.

Questions of interest

A question of interest may be whether or not India will get any 'special deals' from oil-producing countries.

There are two aspects here: price and assured supply. As far as I am aware no oil-producing countries are going to give us special deals involving concessional oil prices anywhere near what they were before the latest Arab-Israeli war. Besides, it would be foolish to expect any of them to agree to do so.

The oil-exporting countries may, however, agree, in bilateral deals, to assure supplies of whatever oil we shall be needing and allow us to pay for them in ways that will not put unbearable pressure on our already difficult foreign exchange position. Some of the ways could be: barter deals; Indian technical assistance and training facilities in various areas for personnel from oil-supplying countries; soft loans on a long term repayment basis for financing our oil purchases and so on. (India has recently signed agreements with Iran and Iraq, but not all the details have been made public.)

Only time will tell how these arrangements, if indeed they are made on the lines indicated, work out in practice. Much will depend on the international situation in the Indian sub-

continent. As long as the situation remains normal we shall have little difficulty with our oil arrangements.

Although one hopes for the best, the possible worst cannot be ruled out or ignored altogether. For example, if another conflict were to arise between India and Pakistan, most of our special deals with Arab nations (and Iran) are likely to be among the very first casualties, irrespective of the issues involved in the conflict or the merits of India's position. India must not overlook this aspect.

Fifth Plan and beyond

Unprecedented rises in prices in 1973 and early 1974 have dealt a shattering blow to most of the fundamental assumptions behind the Fifth Plan. While our planners are busy calculating and recalculating things over and over again—every time with higher prices—chances of prices stabilising at home or abroad, around levels assumed in the final Plan draft, would seem remote.

Energy-wise, things are going to be pretty tough during the period of the Fifth Plan. The problem of evolving a new pattern of consumption in which emphasis on oil is reduced to its proper size, as evidenced by its share in our import bill, is likely to keep us fairly occupied in the coming years. The consequent heavier demands on these two sources are bound to aggravate shortages further, unless some of the steps suggested in this article are taken up. Our performance during earlier Plans *vis-a-vis* targets, under far better conditions than at present prevail, gives one little cause for optimism about India's performance in coming years.

What lies beyond the Fifth Plan will, among other things, depend on how we tackle problems in the near future. If we panic over our oil problems and let our penchant for 'soft options' prevail over good sense, as we have often done in the past, the chances of our breaking out of the circle of energy shortages in future will immeasurably recede—notwithstanding some short term gains that may result from such an approach. Soft options here would mean maintaining our level of oil consumption and present oil-heavy energy policy intact by utilising various funds and lines of credit that are being established around the world, entering into unfavourable collaboration agreements with foreign firms for exploration of oil in India and so on.

If on the other hand, we decide to take up the oil challenge and meet it with firm steps and alternatives available to us from within the country, we could turn this crisis to eventual advantage even if no immediate gains result from this approach.

Petroleum products account for about a third of India's entire energy requirement. Last year we spent Rs500 crores (crore=10 million) to import 16 Mt of petroleum and products. For the same quantity we may have to pay Rs1,000 crores this year. This alone will wipe out half of our total export earnings during the year.

To cut consumption, which had become imperative, the Indian government decided to boost prices of all petroleum products. Two instalments of price increases sent petrol prices soaring from Rs1.74 to Rs3.15 a litre and kerosene from Rs0.75 to Rs1.15 a litre—making Indian petrol the most expensive in the world. (Actually the refinery cost per litre of petrol, even after all the increases in crude prices, is less than a rupee. The rest is all excise duty.)

Petrol and kerosene accounted for only about 11% of the total petroleum product consumption of 25 Mt; the rest (89%) was said to have been used essentially as economic inputs by various industries. Thus, industrialists have argued, any substantial cuts in imports of oil and related products would seriously hamper economic development of the country. The Fuel Policy Committee (FPC, set up in 1971 in the Planning Commission to project a long term energy picture for the country) has found, however, that fuel oil is one petroleum product whose consumption (16% of the 25 Mt used in the

country last year) can be drastically reduced without affecting the level of economic activity. Nearly 70% of the industries using fuel oil, according to the FPC, could switch over to coal without any technological difficulty whatsoever.

In the area of agriculture a 'new strategy', launched during the mid-1960s, sought an increase in output almost exclusively through costly inputs like oil-based chemical fertilisers, and diesel-run tractors and pumpsets. Another matchless piece of Indian planning.

Anyone who knows anything about Indian conditions would know that irrigation, organic manures and human manual labour are far more important and crucial inputs for our agriculture. Notwithstanding this, the consumption of chemical fertilisers, estimated at 19.7 lakh tonnes in 1972-73, is intended to be raised to 52 lakh t by the end of the Fifth Plan (lakh=100,000). This would involve imports valued at more than Rs500 crores in 1978-79 (excluding the crude oil costs). Compare this with the paltry Rs9.0 crores allocated for the development of local manurial sources in the centrally sponsored sectors of the Plan.

It cannot be disputed that chemical fertilisers have a useful role to play in Indian agriculture. But the importance and priority being accorded to them, and the total value of resources committed in this direction will be found to be totally unwarranted in any cost-benefit analysis.

Basically, as far as coal and electricity are concerned, it is a case of demand outpacing availability and supply (by 20% in the case of coal and 10% in the case of electric power). Factors like insufficient rains, maldistribution (of power) and problems involving movement of coal (from production sites to consumption sites far away) have aggravated shortages. There have been other reasons too.

Increasing interest in imported oil as a source of energy had serious and far reaching repercussions on coal use and production. From 33 Mt in 1950 coal production had increased to 67.7 Mt in 1965-66 when stagnation set in because of the increasing use of oil. The output of coal increased by only 8 Mt in the next four years and then dropped for two years in a row to 72.06 Mt in 1971-72. Contrast the 1972-73 production of 79 Mt with the Third Plan target of 98.5 Mt a year in 1965-66.

Power-wise, it has been claimed that the country could have had enough power to meet present demand (and even some to spare) had the Fourth Plan targets been achieved during the period of that Plan itself. We missed those targets, by an incredible 50%. Of the 9.3 million kW capacity targeted for commissioning during the Fourth Plan the actual achievement was only about 4.6 million kW.

Apart from a dismal failure to add new generating capacity, our performance with what we already have has been equally poor. For example, plant availability has been low and transmission losses, which one might think ought to have been decreasing, have actually been increasing. From an

average of 17% in 1968-69, they were up to 18.8% in 1972-73, reaching 30% in some states.

Thermal stations have experienced difficulties in getting coal in a regular and guaranteed manner. Some older thermal plants are unable to get spares for some of their equipment since plants are outdated and such equipment is no longer manufactured in the countries from which they were imported.

Hydroelectric power generation has its own drawbacks, a major one being the utter uncertainty about rains. For example, for two years in a row now, abnormally deficient rains have necessitated sizeable curtailments in power generation.

Our nuclear power programme is still in its infancy. The only power plant in operation today is the 400 MW Tarapur Atomic Power Station in Maharashtra which was built by an American company on a turnkey basis. An unusually large number of problems encountered in its operation have rendered this first experience not an entirely happy one.

A second nuclear power station near Madras, when commissioned, will provide a far better opportunity for correctly assessing our potential and acquired capabilities in this new technology, since this station is to be a totally indigenous effort. But the true impact of nuclear power in India will be felt only when we have developed and mastered (fast breeder reactor) technology to convert our abundant thorium into fissionable fuel for use in power reactors.

Meeting the challenge

To meet effectively the energy challenge facing us at the moment we must do the following things right away: (a) Cut down oil consumption enough to bring import bill down to a reasonable level; (b) step up power generation and increase outputs of coal and mineral oil not only to meet normal growth in demand but also to neutralise the effects of cut-backs in oil consumption; (c) seriously consider making practical use of the 'total energy utilisation' concept in power stations and industries. (This concept visualises utilisation of all the heat produced by burning fuel. At present, power stations utilise only 30% of the heat to produce electricity and the rest is simply thrown away.) I believe that (a) and (b) could be achieved through three things: coal, alcohol and cattle dung. We can, in a number of cases (of industrial and other use) replace oil with coal without much difficulty. Alcohol, or a mixture of alcohol and petrol, can be used to run automobile and other engines with or without modification. (In the latter case the efficiency of the engine is slightly less.) Cattle dung—at present simply burnt after drying—can be fermented to yield combustible gas (methane) and residual slurry for conversion into organic manure, which is richer in nitrogen, phosphorus and potassium than fresh dung or so-called yard manure. The gas can be used for cooking, lighting and running engines to work pumpsets, tractors and grinders, and even for generating electricity.

Soviet thoughts on energy resources

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Nature's Soviet Correspondent shows that the Soviet Union is not being complacent about possible energy problems, large though her resources may be.

ENERGY supplies and resources have always held a prominent place in Soviet planning—Lenin, indeed, defined Communism as "Socialism+Electricity", and the first reaction to the 1973 energy crisis by the Soviet planners was the denial that this could in any way involve them. "The Soviet Union exports annually more than 100 million tonnes

of petroleum and petroleum products . . . The USSR invariably fulfils its contractual obligations and will fulfil them in the future", said the First Deputy Minister of Foreign Trade, Ivan F. Semichastnov, in an interview last January. "Our country is rich in fuel and energy resources . . . In the last 10–12 years the outputs of all forms of fuel have doubled," said the Minister of Power and Electrification Petr S. Neporozhnii in March².

Such comments, duly distributed abroad by the *Novosti* agency, would seem at first glance to indicate that a spirit of confidence prevails in the Soviet energy industry, and that the great industrial expansion envisaged under successive five-year plans is comfortably matched by routine and unhurried exploration and exploitation of the new deposits of fossil fuels.

A closer study of the reports, however, indicates a less propitious picture. The Soviet Union will fulfil its contractual obligations to deliver fuel but as regards her

achievements commended are themselves an indication of the need to exploit all available power resources. Thus on March 5, 1974, *Novosti* reported the selection of a site for a 3,200 MW power station on the river Vakhsh in Tadjikistan (a site where seismic activity reaches magnitude 9, necessitating the placing of the station underground), followed by the description of a new town, Komsomolsk, to be built in the permafrost zone, near a rich deposit of coking coal—the town to house 70,000 inhabitants, the coalmine to produce an estimated 4.5 million tonnes (Mt) a year. In introducing a 'round table' discussion on the prospects of MHD generation of electricity, published in *Nauka i Zhizn*³, Academician Vladimir A. Kirillin, Chairman of the State Committee for Science and Technology, commented: "It is sufficient to say that the increase of the efficiency of thermal power stations by even 1% on the scale of our country at the present level of production of electric power would save approximately 3 million tonnes of fuel

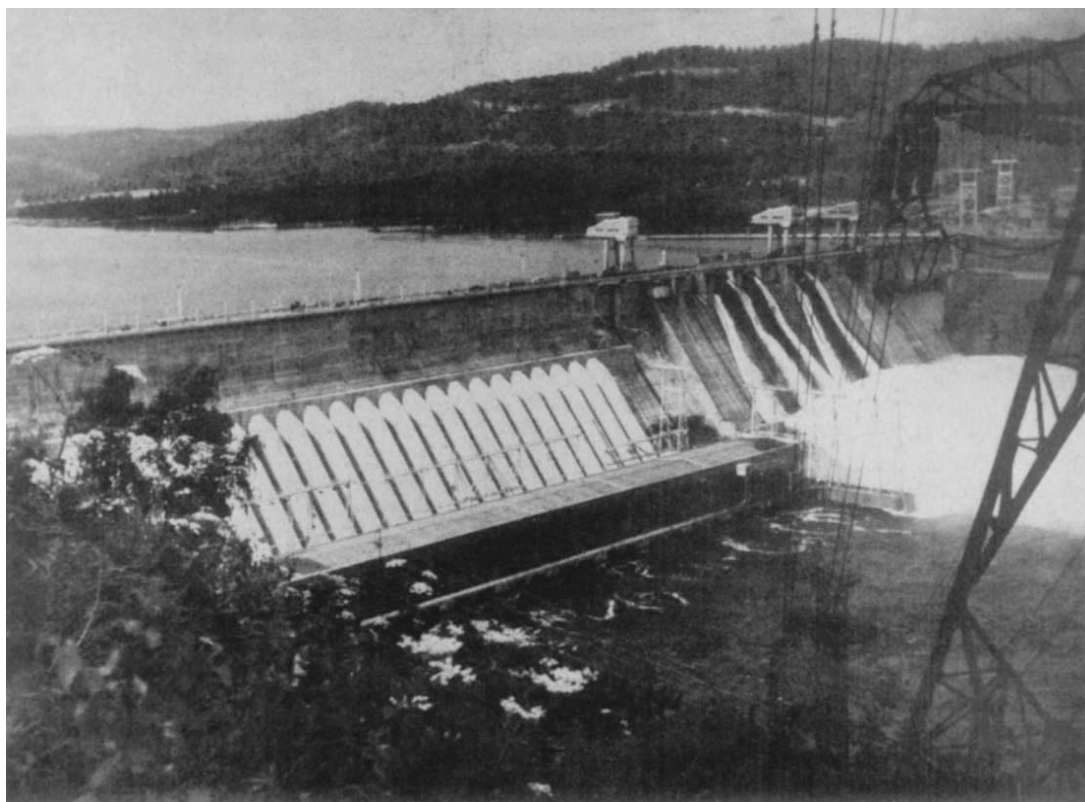


Fig. 1 The Krasnoyarsk hydroelectric power station on the River Yenisei in eastern Siberia.

further expansion "this is not envisaged at the present moment"¹. The vast resources of fossil fuel are "extremely nonuniformly distributed", being mainly in the eastern regions of the country with only 10% in the European part of the USSR and the Urals where 80% of Soviet industry is concentrated². The almost daily accounts in *Pravda* of the completion of a section of pipeline or the commissioning of a power station suggest an underlying concern. So, too, do the *Novosti* reports, designed for foreign consumption, which from the beginning of this year have increasingly emphasised the healthy state of the Soviet energy situation. Coverage has varied from straight reports on new power stations, gas fields or pipelines to such details as the use of tea wastes to lubricate oil drills, air-cushion transport of heavy mining gear in the tundra, or the automatic deicing of high voltage power lines in the extreme conditions of Sakhalin Island. Indeed, many of the

per annum . . . or . . . would produce an additional 10,000 million kilowatt hours of electrical power."

Future supplies

It would seem, therefore, that in spite of the reassurances of the politicians, considerable thought is being devoted by the Soviet energy experts to the true state of their "in-exhaustible" energy supplies. A lecture given by Academician Kirillin, during his recent visit to Britain⁴ served only to emphasise this point of view.

At present, he said, more than 80% of the electric power in the USSR is generated by thermal power stations, using chemical fuels, mainly coal. Although the majority of the new power stations to be built will be based on nuclear power, a certain number of conventional power stations will be built in the future. These will almost all be coal fired; in spite of the increased proportion of oil and gas

in the overall fuel output of the Soviet Union (an increase from 51% to 65% in the period 1965–74), the natural resources of coal far exceed those of oil and gas. New gas-fired and oil-fired stations will therefore be built only where coal-fired stations would involve too great a pollution hazard, notably in cities. At present, indeed, there is an increasing emphasis on the importance of the coal industry in the Soviet Union, especially on open-cut mining, which makes the economic efficiency of coal production comparable with that of oil and gas.

(Some recent comparative statistics provided by the *Novosti* agency are of interest: the absolute output of coal in the Soviet Union is increasing by some 100 Mt every five years; the share of open-cut coal in the total coal output, it is estimated, will increase by some 30% in the current year. Considerable attention is being paid to lignite resources, as well as to those of 'black' coal; a recently discovered lignite seam in Byelorussia—conveniently near the industrialised areas of the USSR—is estimated to hold some 50 Mt of fuel, accessible by open-cut mining.)

The use of gas-fired and oil-fired power stations is also indicated, said Academician Kirillin, for peak-hour booster stations. This seems at first glance a somewhat strange admission; according to Minister Neporozhni², the projected supergrid, which will unify the entire power production of the Soviet Union and the Comecon system into a single network, and which should be completed in the next 18 years, is intended, *inter alia*, to obviate the whole peak-hour problem. The considerable time differences between the various parts of the USSR should mean that with the unified supergrid, electricity could be transferred from power stations at local 'off-peak' to consumers in a 'peak' zone, thus saving some 35–40 GW of generating power (that is obviating the need to build power stations to that capacity). But Academician Kirillin seemed less confident. Questioned on the subject, he stated that only some 2 GW could be transmitted by the supergrid as envisaged, and that until superconducting transmission lines become a practical possibility, the need for booster stations will remain—an interesting example of the dichotomy between the claims of the planners and the tasks of the engineer.

Further elaborating on peak and semi-peak boosting, Academician Kirillin indicated that MHD (magnetohydrodynamics) stations are considered as a promising energy source in this field. Generation by MHD is, in fact, one of the specific fields of cooperation between Soviet and United States specialists, which has been developed under the open-ended agreement on technological cooperation of May 1972. A meeting held in Moscow in February and March 1974 resulted in the signing of a protocol on a programme of joint work to design, build and put into operation commercial MHD units. The Soviet team, headed by Aleksandr E. Sheindlin, Director of the High Temperature Institute of the Soviet Academy of Sciences, has already designed and constructed what they describe as an "experimental commercial" MHD generator, the U-25, and on the basis of this work, together with research data, they envisage the commercial operation of MHD stations by the mid 1980s with an efficiency of some 10–15% of that of conventional thermal power stations. Dr Bill Jackson, who signed the protocol on behalf of the United States delegation, observed that the problem of MHD generation is essentially now one of engineering rather than basic research and said that the U-25 generator marks a breakthrough on the engineering side. It should be noted, however, that the Soviet estimates on the efficiency of MHD generation are considered by many western experts to be unduly optimistic.

Nuclear power

Regarding nuclear power stations, the same optimism seems to prevail. In his lecture, Academician Kirillin stated that

"most experts believe that extensive construction of nuclear power plants with fast-neutron reactors will not be a practical possibility before 1985"—a somewhat early date, even as a *terminus post quem*. The present generation of Soviet nuclear power stations are mostly of ²³⁵U thermal neutron type, either water-moderated water-cooled vessel reactors, or channel graphite-moderated reactors. The latter are of special importance since they can be used as breeders of the plutonium required for the various fast breeder reactors which will form the next generation. One such fast breeder reactor, the BN-600 is already operating (at reduced capacity, because of teething troubles) at Shevchenko on the Caspian Sea, as a source of combined power generation and water desalination. A second BN-600 is under construction. In view of the difficulties which have arisen in the sodium cooling circuits of the Shevchenko reactor⁵, it is noteworthy that Academician Kirillin observed that "probably it would be desirable, side by side with the creation of fast-neutron reactors operating with sodium coolant, to speed up the development of this type of reactor with a gas coolant."

Other sources

The other major source of electric power in the Soviet Union is, of course, water power. This has played a considerable part in the opening up and industrialisation of Siberia and the Soviet Far East. This programme is still continuing, with such major prestige projects as the 6 GW Krasnoyarsk power station (the largest hydroelectric plant in the world).

Hydroelectric power plants are now planned in conjunction with other projects—land reclamation, irrigation, and the planning and development of specific industrial centres (for example, the giant aluminium plant at Krasnoyarsk, which consumes one-third of the output of the hydroelectric plant). According to Academician Kirillin, projects are now under discussion for hydroelectric peak booster stations, in which the water is pumped up to a high level by a thermal power station at off-peak time, to be released again at periods of maximum demand. The high costs of such schemes, however, would limit their use only "to areas of favourable terrain".

Regarding such suggestions as the large scale use of solar energy or the Earth's heat (detailed projects for which appear from time to time in the semi-popular scientific press in the Soviet Union⁶) while admitting that their study constitutes an "urgent problem", Academician Kirillin considered that only with "principally new methods" could they yield adequate large-scale results, although on the small scale, for fruit drying or local heating, for example, some useful results have been obtained. Similarly, wind power, tidal power and the like lie, at present, outside the bounds of practical possibilities.

Although further research is needed in these fields, therefore, the main problem before the Soviet power generating industry at present is, in his opinion, two-fold: on the one hand, the more efficient utilisation of conventional thermal power stations—including the use of combined steam-gas turbines, and district heating schemes using the steam from power stations—and, of course, the improvement of anti-pollution measures and on the other, the greater development of nuclear power, including controlled thermonuclear fusion which, he considers, should be available as a source of industrial power generation by the end of the century.

¹ *Novoe Vremya*, No. 2, 7-8 (1974).

² *Novoe Vremya*, No. 9, 14-16 (1974).

³ *Nauka i Zhizn'*, No. 4, 15-23, 40 (1974).

⁴ *Power Industry of the USSR, Its Present and Future*, a lecture delivered at the Culham Laboratory of the UKAEA, May 23, 1973.

⁵ *Nature*, **248**, 95, 468 (1974).

⁶ *Priroda*, No. 5, 95-103 (1969).

Making energy value for money

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The National Industrial Fuel Efficiency Service Ltd, once a British Government body but now a successful private company, pays close attention to an energy problem that is often ignored.

EVER since the Industrial Revolution, people have tried to improve the use of energy, and countless patents have been issued for devices to economise on the amount of fuel needed to carry out particular work loads. Some of these, such as mechanical stokers and economisers, were invaluable; others were frankly useless, but by high pressure sales methods were sold in large numbers. Even today fuel users must be puzzled at the claims made for some articles which are alleged to save fuel.

Traditionally the industrialist has regarded his energy requirements as a factory service or, at best, as one of the tools of production. His main concern has been the final cost of purchased fuels or electricity per unit of production, insofar as this influenced his ability to compete. Since in most industries this cost has been a relatively small proportion of total production costs his concern has not been of very high priority.

Until recently the continuing availability of the necessary energy sources, in some suitable form, has been taken for granted. True, there have been some short term crises of supply of specific energy sources, but these have been of limited duration and the worst effects have often been mitigated by a temporary or permanent change to other available fuels.

The demand for energy all over the world has continued to increase without interruption since the end of the Second World War, and fortunately this increase was mainly met by the rapid expansion of oil production which, as far as Europe was concerned, meant the Middle East and African countries. The price of fuel oils dropped steadily in the postwar years and was stable for a surprising period in spite of steady rises in the cost of living and of industry's other raw materials. In turn this tended to stabilise other fuel prices, and indeed forced the contraction of the coal industry in the rest of Europe as well as in Britain.

Gas, regarded for all its life as a high price fuel which was only justified where cleanliness, convenience and improved production could justify its costs, dropped suddenly in price to industrial users after 1968 and became a serious competitor, in large scale use, to coal and oil. Unfortunately domestic consumers were not so lucky, as the very high cost of the conversion of their appliances to the use of natural gas together with other inflationary factors, prevented any real reduction in price to them.

Now, in less than a year, the price of oil fuels has rocketed, mainly because the Middle East countries have accelerated demands for participation and increased royalties but also because of the increased costs of such things as transport and refining. Oil fuels have increased roughly three-fold in price to industrial, commercial and domestic consumers alike, and the costs of other fuels have also risen rapidly partly under the influence of 'supply and demand' and also because of large wage increases and investment problems.

Almost at the last moment the industrialist is beginning to take a fresh look at his energy requirements and give this its true place in his priorities. After all, if these energy requirements are not met he will be out of business. In many cases almost for the first time, the industrialist is asking himself the questions:

- What is this industrial energy?
- What is the present situation?
- What should the World, the European Economic Community (EEC) and Britain do about it?
- What can individual companies do?

The answers to some of these questions involve a great deal of speculation. On his answer to the last question could depend the industrialist's competitive position or even his very existence.

We can hope that the recent discoveries in the North Sea will prevent any immediate shortage of supply, but the length of time granted to Britain will depend on the rate of exploitation. An accountant would argue that, if it were technically possible, the best financial recovery on the thousands of millions of pounds being invested would be to extract all the oil and gas in the minimum possible time. This would obviously more than satisfy British demand in these few years and the surplus could be sold to assist balance of payment problems. Such uncontrolled rapid exploitation would in passing be the final blow to the coal industry. There is a better, national argument to extend the period of exploitation, to keep the coal industry at a healthy and relatively steady level of production and so conserve resources to last over a longer period so that other sources of energy can take over as the North Sea's output declines. Nuclear power stations can, and will, be developed to reduce the demands on coal and oil for electricity generation but these need both capital and time to construct and we may well see other new forms of energy production developed such as solar, geothermal, tidal, nuclear fusion and wind power.

All these points so far have been concerned with the supply of fuels and energy, but disregard the effect of price. It is doubtful whether fuels will ever be as cheap again, relative to other costs, as coal and oil have been over the past twenty years. Although it has been argued that actual shortage is unlikely over the next twenty or more years, all fuels will be expensive. Of course it is easy for many companies to pass on the extra cost of fuels as just another of the rises in raw materials prices that cause the cost of their products to increase, and unfortunately many manufacturers seem to be doing just this. While demand exceeds supply, and for many companies this is the situation for a year or so ahead because of the reductions in output caused by the three-day week and cuts in electricity usage of recent memory, such a policy of passing on price increases works. This does not help the consumer, however, and it encourages wage claims.

Also, all our past history of surpluses and shortages indicates that fairly soon many manufacturers will have caught up with their order books and may be chasing customers. There are also services, such as hospitals, local authorities and government, and the domestic consumer, who manufacture no saleable product and so cannot pass on the large increases in fuel and energy costs. These must fall on the

whole community as increases in rates, taxes or personal spending.

Energy conservation can help by minimising the increases in costs of fuels and by reducing the demand so as to extend the period for which the finite resources of conventional fossil fuels will last. The National Industrial Fuel Efficiency Service, NIFES for short, as the most experienced organisation in the field has been able to demonstrate for more than twenty years that large savings can be made. Unfortunately during the era of cheap fuel and energy many companies and authorities have paid little attention to possible savings on a fuel bill which might have been less than 5% of their total running costs, preferring to spend their own staff time, use of outside advisory services and restricted capital resources on other facets of their costs.

A committee which considered fuel efficiency and conservation once said: "The committee reached the conclusion that the gap between fuel requirements and home production would continue to increase and there was the possibility that a critical shortage of fuel would arise. The committee recognised that the nation's economic progress and well-being would depend on fuel and power and that it was vitally necessary to make the most effective use of available supplies". How topical this sounds, and yet these opinions were those of the Ridley Committee of 1952. The wartime Ministry of Fuel and Power had operated a fuel efficiency service and this had continued after the war. Periodic bulletins on various aspects of fuel utilisation, issue of a regular newsletter and provision of a free first-aid advisory service by a staff of around 100 professional engineers and technicians was offered to industrial and commercial fuel users.

The results of these visits were so encouraging that the ministry decided to extend the service so that more detailed surveys of fuel usage could be carried out, both in the boilerhouses context and, more important as it turned out, in the realms of process and space heating. Fees were charged for these detailed surveys and a considerable demand developed from the inception of these 'mobile testing units' in 1948.

After the report of the Ridley Committee, the minister decided to set up a fuel advisory service which would operate outside the Civil Service structure, and so NIFES commenced operations in 1954. In the earlier years much of the running costs came from contributions from the National Coal Board, and the Gas and Electricity Councils, with small additional sums from certain oil companies and the Government of Northern Ireland. These contributions were progressively reduced as NIFES developed its own fee income and in 1969 the government took over responsibility, providing a much reduced and tapering three-year grant on the understanding that the company would become self-supporting.

In the early years, its activities were entirely concerned with fuel problems, using poor quality fuels in many boilers until better fuels became available, carrying out tests on existing boilers, furnaces and processes so that recommendations could be made to improve performance or reduce fuel costs, training boiler operators in correct firing and supervision and giving advice on numerous other fuel problems. Inevitably, as recommendations were made on existing plant and on its possible replacement, many clients expressed the view that the knowledge and experience of NIFES would be of great value to them when new factories or premises were to be constructed or when new plant was to be installed. The company was encouraged by such clients to move into the field of design engineering and advise on all aspects of such capital projects, and for many years now has been handling this field of consulting engineering as part of its activities.

Unfortunately this reduced grant meant that certain services in the education and training fields had to be cur-

tailed, since they had been offered for many years at nominal fees to encourage interest in fuel efficiency and higher productivity. It was found that the demand dropped considerably when fees reflecting the true cost of providing such educational services were asked. One item of which the company is particularly proud is the Boiler Operators' Handbook, which was originally produced as the New Stokers' Manual in 1959 and has been revised and extended in several editions. Nearly 50,000 copies have been sold, and a steady demand still persists for this unique aid to the boiler operator. Nearly 17,000 men throughout industry and the public service have been trained in operation, maintenance and utilisation of plant, and more than 10,000 of these reached the standard of the City and Guild's Boiler Operator's Certificate.

At the end of 1971, the government had decided that NIFES should continue as a private company, but be organised so as to offer all the types of service then being carried out. It is pleasing to record that the staff were so confident of the viability of the company that they were able to agree amongst themselves to raise a share capital and give certain further financial guarantees so that the government agreed to sell the assets and goodwill. As a result the work of NIFES continued without interruption and with the same staff. Modest profits have been made in each of the first two years of private operation and the engineering staff has increased by around 25% since the government handed over ownership.

What is the present company offering? First, there is the enormous amount of experience. Many of the present staff have been successively with the Fuel Efficiency Branch and NIFES and others came from other industrial connections to NIFES many years ago, so that a good proportion of the staff have more than twenty years of experience in fuel, process, heating and allied problems.

The service has always offered to its thousands of clients an impartial advisory and testing service, at first concentrating on fuel and heat problems but very soon expanding into many allied fields. It pioneered the idea of energy measurement and costing and with a unique feedback system of its wealth of experience over the whole diverse range of industrial, government department, hospital and local authority work, it can claim to be able to present a client with the likely operating characteristics of a new plant before it is built. Unfortunately the myth of reliability of fuel suppliers has also been exploded in recent years by strikes and other industrial action and NIFES has helped many companies to install standby electrical supplies or dual-fuel systems, often showing that the cost of standby plant can be turned to profit by using it to avoid peak load charges.

In 1969 an independent survey of the results obtained by NIFES advisory and testing services was carried out and showed that in the first fifteen years of activity total fuel savings were at least 20 million tons of coal equivalent, and these are continuing savings because of alterations in process or production, or the running of existing plants at higher efficiency. The survey concluded that for each man-day spent on investigations and surveys by engineers, the resulting recommendations saved 20 tons of coal or its equivalent a year, much of which would continue to be saved each successive year. Since 1969 many further visits and surveys have been made, and a very conservative appraisal now suggests that some 30 million tons of coal equivalent have now been saved.

If the whole of industry raised its standards of energy utilisation, within practical limitations of scale, to that of the more efficient companies, an annual saving of more than £350 million could readily be made by known and proved techniques and practice which are financially viable even at today's energy costs. This is in fuel costs alone, and at 1974 fuel prices. There would also be inci-

dental savings in many cases because of reduced replacement, maintenance and labour costs, better working conditions and production improvements. Reduced pollution would also result from improved and more efficient fuel usage.

Heat and power surveys carried out over a reasonable sample of industrial groups indicate the potential savings shown in Table 1. The figures do not include the further savings possible by improving thermal insulation standards.

Table 1 Potential fuel savings

Industrial group	Mean saving (%)
Ceramics, brick, glass	15.0
Chemicals	18.0
Iron and steel	20.0
Engineering and metals	18.0
Textiles and leather	15.0
Food, drink and tobacco	15.0
Other manufacturing	21.0

The Thermal Insulation (Industrial Buildings) Act 1959 is one example of legislation which has made a positive contribution to energy conservation during the past 14 years. These standards are inadequate in the light of higher comfort standards, higher fuel costs and energy shortage. They are, in fact, among the lowest in Europe.

The regulations should be brought up to date by:

- Specifying lower standards of heat loss for roofs to reduce losses to half the present permissible figures.
- Extending these standards to cover walls also.
- Applying them to existing buildings, say over a period of seven years, as well as to new buildings.
- Extending the definition of buildings to include commercial and local authority buildings.
- Making some measure of control of space temperatures mandatory.
- Insisting on higher insulation standards for commercial and domestic buildings.

Such a policy would reduce the yearly usage of energy in Britain by at least 6 million tons coal equivalent and with rising fuel costs would be an economically viable proposition in the majority of installations. This takes no account of similar possible high savings on domestic premises.

There is an inbuilt financial incentive in energy savings. An exhaustive NIFES survey in 1965, covering industrial establishments, proved that a total capital investment of £2.5 million in new and modified plant yielded a saving of 300,000 tons coal equivalent a year. The payback period

was two years for the sample taken. Although the capital expenditure nowadays would be substantially higher, fuel costs have risen much faster than the cost of energy-using equipment. (As the present high rates of interest have a deterring effect on investment in plant not directly associated with production, there would seem to be a case for reintroducing special investment grants for capital outlay on energy-saving equipment.)

Finally, a few examples where savings have been made. At a Midlands steelworks engaged in the production of stampings, tests were made on seven oil-fired bar heating furnaces. Defects were found on some burners, there was scope for further insulation and the design of the furnaces could be improved, even though the overall performance was as good as the average for this industry. With the cooperation of both operators and management, modifications were made. On a typical furnace, throughput was increased by 14% and oil consumption reduced by 15%, so that furnace performance measured in gallons of oil per ton of throughput improved by 25%.

At a gelatine factory a campaign was undertaken which covered reorganisation of the steam distribution, replacement of steam traps and improvements in recovery of hot water, tests on evaporators, boiling tanks and driers to improve their performance and reuse waste heat in other parts of the process, setting up a record system to examine daily steam usage in departments and reorganisation of the distribution of cooling water. This resulted in a reduction of 29.5% in the amount of steam used per ton of gelatine produced.

Whisky distilleries traditionally operated with stills heated from below by hand-fired furnaces using expensive large coal. For many years NIFES has cooperated with a number of distilleries in a quiet revolution in the whole whisky-making process. Several have converted their stills to steam heating, using highly efficient boilers, and to fullscale waste heat recovery systems to reduce dependence on rivers and streams for cooling water. At these converted plants, fuel savings of 50%, and in some cases slightly more, have been made without any change in the character of the whisky produced.

A company making glazed clay sanitary pipes were experiencing difficulties in drying larger sizes after the moulding process so that they could be fired and glazed in the kilns. After a series of tests modifications were suggested to drying procedures, using high humidity enclosed drying chambers for the first few hours. This reduced the proportion of cracked and unsaleable pipes from 45% to 5%, so that although there was little effect on fuel usage for drying, saleable production was almost doubled.

Nuclear fission as a general source of energy

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Heat from nuclear reactors can be used for several purposes other than the generation of electricity, for example as a source of heat for chemical processes or for producing 'synthetic' fuels.

THE total world consumption of energy is at present running at an annual rate of about 2×10^{17} kJ most of which is derived from fossil fuel sources. This is approximately 0.2 Q a year where the unit $Q = 10^{18}$ BTU = 1.054×10^{18} kJ is a convenient measure in talking of world energy consumption. The incident solar energy over the surface of the Earth is 5,200 Q a year. Estimated coal reserves would be sufficient to meet this rate of consumption for about 1,000 yr but the calculated

reserves of crude oil and natural gas would be barely enough to satisfy such a demand for 100 yr.

The pattern of utilisation of primary energy sources is, however, not compatible with their availability, oil and natural gas being preferred, to the extent that about two-thirds of our power is now derived from these. This has been a natural consequence of the fact that until recently they have been cheaper and more convenient to use than solid fuels and easier to transport over large distances.

Electricity plays an ever increasing role in the energy mix, but the present world consumption, about 6×10^{12} kW h a year, corresponds to only about 10% of the total primary energy supply. This ratio is certain to increase in the future but the extent to which it may do so is limited by a number of important factors which have to do with the problems of storage, portability and transmission of electricity. Economic considerations generally dictate that electricity should be generated in large centres from which it has to be distributed by overland transmission lines. The range of distribution is limited by the fact that such lines are expensive and losses are high. In this respect it is much more economic to transport energy over large distances in the form of liquid or gaseous fuel.

No large scale method of storing electrical energy at an acceptable cost has yet been developed and this, of course, results in poor utilisation of expensive electricity generating plant, arising from fluctuating load requirements. There is no corresponding problem in the storage of primary energy in the form of oil or gas, of course, and these may be converted locally into the energy form required as the demand arises, including the generation of electricity with relatively inexpensive small plant such as gas turbines.

Except in the case of railways, electricity is relatively useless in transportation because of the problems of devising reasonably light and compact forms of storage. These problems must be regarded as completely insoluble in the cases of aircraft and ships and practically so for fast long distance road transport. The reason is quite fundamental, namely, that only a liquid fuel can meet the requirement of energy carried per unit volume and mass in these cases.

The foregoing considerations suggest that however far we may go in utilising energy in the electrical form, there will always be a requirement for liquid or gaseous primary energy supplies in at least equivalent amounts. This is important in considering the possibility of utilising nuclear energy to replace the dwindling resources of fossil fuels. Up to the present, nuclear fission has been seriously considered only as a source of energy for electrical power generation, but as we have seen this will not meet the total demand for directly usable energy and almost certainly not even the major part of it. It is necessary in the circumstances to consider the ways in which the heat generated by nuclear fission may be more fully utilised to meet the overall needs and not merely to generate electricity to be supplied through the grid.

Scope for nuclear reactors

In looking beyond the use of nuclear reactors exclusively to generate electricity, it is necessary to examine possible applications in the following categories:

- (i) the direct use of waste heat in the thermodynamic cycles involved in generating electricity (low temperature processes);
- (ii) the direct utilisation of the heat output of reactors in chemical industrial processes supplemented by electricity production (high temperature processes);
- (iii) direct or indirect application of nuclear heat supply to produce synthetic liquid or gaseous fuels (high temperature processes or methods involving intermediate electrical power generation).

The average efficiency of energy conversion from heat into electricity at present is about one-third. In the application of nuclear fission this figure is barely matched by water-cooled systems, because of the low steam inlet temperature in the power cycle, not exceeding 300° C, compared with around 550° C in

modern fossil-fuelled stations whose net efficiency may be about 40%. The residual heat, amounting to 60–70% of the total, is wasted and its dissipation often presents embarrassing problems. Considerable attention is now being paid to the utilisation of this reject heat, notably for district heating and possibly for desalination.

The widespread utilisation of the waste energy for district heating is inhibited by the problems of siting central electricity generating stations in appropriate population and industrial centres, where the demand is likely to match the availability of the heat. Social, technical and economic problems are certain to limit the scope for adopting this practice on a large scale, at least in the foreseeable future. Apart from this limitation, however, technical considerations have to be taken into account.

In normal steam cycles the peak temperature of heat rejection is low ($\sim 50^\circ\text{C}$) and effective use of the waste heat requires that this should be raised. Reduction in the efficiency of the cycle in producing electricity is acceptable if the reject heat is being utilised, so that it is permissible to raise the back pressure of the steam and the condenser temperature. This merely implies trading electrical energy for useful heat. It is, however, obvious that there is much less scope for doing this in the low temperature cycles of water-cooled reactors than in modern conventional steam cycles whose source temperatures exceed 500° C.

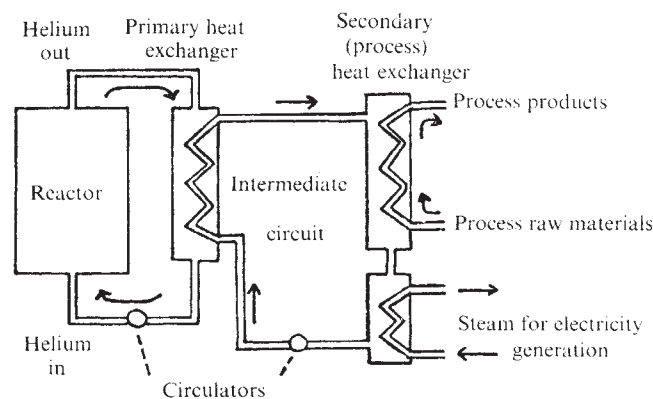


Fig. 1 Direct cycle with utilisation of waste heat. Helium temperatures: 1, $\sim 950^\circ\text{C}$; 2, $\sim 200^\circ\text{C}$.

The greatest prospects for utilising the reject heat of power conversion undoubtedly lies with the adoption of the high temperature reactor used in direct cycle with a gas turbine. In this system (Fig. 1) the helium acts as the working fluid in the thermodynamic cycle and expands through a turbine which drives the electricity generator. This power cycle, with a turbine inlet temperature of 950° C and an efficiency of conversion to electricity slightly in excess of 40%, would involve heat rejection at a peak temperature around 200° C. Such a high temperature would not only facilitate the utilisation of the waste energy of the cycle for district heating but would introduce possibilities for applying the heat, in a variety of industrial processes. Furthermore, in this system, the potential will exist for increasing eventually both the turbine inlet and the heat rejection temperatures while maintaining the efficiency of the cycle in terms of electrical power output. In this way it would be realistic to consider the application of waste heat in processes requiring heat (possibly as steam) at temperatures up to 250° C or perhaps higher.

Turning to the second category of possible applications of nuclear energy, we have a procedure in which the hot coolant emerging from a reactor is used to provide thermal energy directly in some high temperature industrial process. This is the so-called process heat application of nuclear reactors, which, clearly, is only meaningful if it is associated with the use of the high temperature gas-cooled reactor. So far the technical and

economic feasibility of using reactors to provide heat directly in this manner has only been considered for a limited number of processes, of which the steam reforming of methane and its application in iron ore reduction has received particular attention.

The application of nuclear heat in the steam-methane reforming process would involve using a nuclear reactor to heat helium to a sufficiently high temperature and transferring the heat from the helium to a mixture of methane and steam in an appropriately designed heat exchanger in which these latter gases would be brought as near as possible to the peak helium temperature, in the presence of a catalyst. A range of temperature from 750° to 950° C is estimated to be required for this purpose. The immediate chemical-reaction products in this process are hydrogen, carbon dioxide, carbon monoxide and residual steam and methane, which must be cooled to an intermediate level at which carbon monoxide can be reacted with additional steam to convert it to carbon dioxide. Further cooling to ambient temperature would be required in order to remove the carbon dioxide, residual water vapour and any higher hydrocarbons that might be present, leaving a mixture of hydrogen and surplus methane. Low temperature separation of methane from the hydrogen can leave the latter in a fairly pure state.

If the hydrogen were required to be used in ore reduction it would be reheated in the same plant, in counterflow regenerative heat transfer with the cooling products of the reforming process and further heat from the reactor helium added as necessary for the ore reduction.

The use of hydrogen and nuclear heat to reduce iron ore to sponge iron is an attractive alternative to the present process which uses coke both as a fuel and as a reducing agent in blast furnaces. This arises from the high cost and scarcity of coke in many parts of the world. But natural gas, which is likely to be a rapidly disappearing commodity early in the next century, can hardly be regarded as a satisfactory source of hydrogen in the longer term. Consideration of this brings one into the third and perhaps most important category of nuclear energy applications, that is its use to produce substitutes for the liquid and gaseous fossil fuels. It has been pointed out that these latter currently dominate the primary energy supply situation and that we must expect that the role of liquid and gaseous fuel will not significantly diminish in the future despite considerable increase in the utilisation of central station electricity. Because of this one should think in the future in terms of central energy stations which will export not merely electricity, but also liquid and gaseous fuels and that, in fact, the energy content of the latter may considerably exceed that carried by the former.

The ultimate key to the provision of substitutes for oil and natural gas lies in the intermediate production of hydrogen. In principle, this involves the absorption of energy in water to split it into its constituents. The established method of doing so, of course, is by electrolysis. In going from nuclear heat to hydrogen in this way, however, two efficiency factors are involved, namely, the efficiency of electricity generation and the efficiency of the electrolysis process. The former would be as low as 30% for water-cooled reactors, whereas the latter on the basis of existing technology is 70% at best, implying that the hydrogen product would carry only about 20% of the original thermal energy released. There is scope for eventually improving on this overall efficiency by a factor of two, partly by developments in the electrolysis process and partly by substantially increasing the efficiency of electricity production which should be possible as a result of longer-term developments of the high temperature reactor with direct gas turbine or dual cycles.

To achieve a hydrogen yield corresponding to more than 40% of the input thermal energy, however, would require the adoption of a pyrolysis process, directly utilising the nuclear heat to split the water. Direct thermal decomposition

of water is ruled out in so far as it would require a temperature of about 4,000° C to give a high yield of hydrogen by this means. But it is possible to devise sets of chemical reactions involving various reagents whose net effect is to consume water and produce hydrogen while regenerating and recycling the reagents. Many such sets of reactions, involving three or four stages, are now known and can proceed at temperatures lying within the capabilities of the helium-cooled high temperature reactor; they offer the real possibility of producing hydrogen from water in a direct nuclear process heat application.

An alternative route to hydrogen production exists while solid fossil fuels remain in reasonable supply, which is likely to be the case over the next century, namely, the gasification of coal and lignite. The conventional steam-oxygen process of producing hydrogen from coal involves burning some of the coal with the oxygen to produce the heat required for the steam to react with the remaining carbon producing initially hydrogen and carbon monoxide, the latter being subsequently reacted with additional steam to produce carbon dioxide and further hydrogen. Methane is an alternative product obtained by reacting some of the hydrogen with the carbon dioxide, carbon monoxide or the coal itself. The heat used in the endothermic steam-carbon reaction, of course, is transferred internally from the coal burning in the oxygen in the same bed.

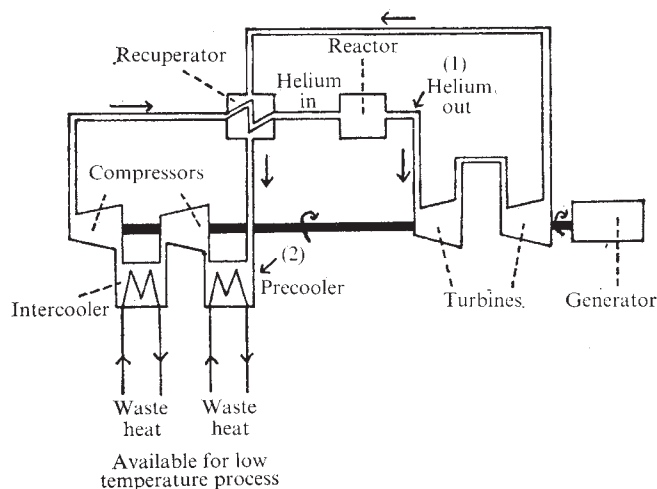


Fig. 2 High temperature process heat application.

The application of nuclear energy would involve externally heating the reaction vessel by means of hot helium instead of the internal combustion of some of the coal. By using external nuclear heating the yield of hydrogen from a given amount of coal could be about 45% higher than that obtained by the conventional combustion method. This important reduction in coal consumption would provide sufficient incentive to adopt nuclear heating which would otherwise have to be justified on questions of cost, with the much higher capital investment of the nuclear plant being weighed against the high cost of the additional coal required in the steam-oxygen process.

Considerable differences of opinion exist in estimating the temperatures required to gasify coal by reacting it with steam. Most experts consider that the peak temperature of the reacting materials would need to exceed 1,000° C for the process to proceed at an economic rate with hard coal and perhaps 900° C in the case of lignite. Lower temperature gasification is possible by reacting the coal with hydrogen to form methane (an exothermic process) and using nuclear heat in the steam-methane reforming process to produce hydrogen, part of

which is then recycled to react with the coal. There is a net production of hydrogen in this process which is the same for a given carbon consumption as in the steam gasification, with the alternative possibility of extracting this net yield in the form of methane. This process would be more attractive than steam gasification if it were not for the fact that a substantial fraction of the coal defies attack by the hydrogen and remains as a char. Success of the process depends consequently on the eventual possibility of being able to convert the char or otherwise use it as a source of carbon or energy.

Technical requirements

The discussion so far in this article has concentrated on the problem of using nuclear energy to produce substitutes for the liquid and gaseous fossil fuels which play such a vital role in supplying our energy requirements. There are many other possibilities for using high temperature heat from nuclear reactors to carry out industrial processes on site and many of these may prove to be commercially attractive. The important fact which emerges in a consideration of these is that they will call for substantially higher helium temperatures than are needed for steam cycle electric power generation. In the latter case a reactor outlet temperature of 750° C is ample to generate steam at say 550° C. If, however, one is to provide heat for chemical processes ranging upwards from about 750° C we have to contemplate the achievement of reactor outlet temperatures of at least 950° C. This would allow for the use of an intermediate heat transfer circuit, with a primary heat exchanger transferring energy from the reactor helium to helium in the intermediate circuit, and a secondary process heat exchanger transferring heat from the intermediate circuit to the reacting materials in the chemical plant. The purpose of the intermediate circuit is to provide a safe isolation between the slightly radioactive primary helium and the hot, chemically active materials in the process plant (Fig. 2).

The feasibility of achieving helium temperatures from the reactor core in the region of 950° C has already been firmly established. In fact, the AVR at Jülich in the German Federal Republic is now operating at that temperature and in the Dragon Reactor Experiment helium emerges from the hottest channels at temperatures in the range 1,000°–1,100° C. Developments in fuel and core materials technology lead to the expectation of mixed helium outlet temperatures perhaps as high as 1,200° C in a few years. The problems of handling gas at such high temperatures elsewhere in the reactor primary circuit, and to a lesser extent in the intermediate circuit, are, however, quite formidable. Thermal insulation will be an aspect presenting many difficulties but undoubtedly the major problems will be associated with the interface heat exchangers, particularly the primary ones. It may be necessary to depart from the more conventional use of metals and go to ceramics or graphite in heat exchangers where the surface temperatures exceed about 1,000° C.

There would also be temperature problems to some extent in the cooler arms of both primary and intermediate circuits of nuclear process heat plants. This is because it is not convenient to have helium above about 350° C in those regions which contain the circulators, control machinery, and so on. The helium temperature drop across the process heat exchanger may be only in the range 200°–400° C so that it will emerge too hot for convenient recirculation. For this reason it would be desirable to take the helium from the high temperature process through a further stage of useful heat removal, most probably in providing the steam to generate electricity so that the plant serves a dual purpose.

Availability of nuclear fuel

It has been assumed here that nuclear fission might be used as a more or less complete energy substitute for fossil fuels. Such an assumption, apart from technical and economic factors, is only valid if the exploitable resources of fissile material are many times greater than those of fossil fuels. The workable reserves of the latter are estimated to be about 200 Q which corresponds to about 2.5 million tonnes (Mt) of fission. In a situation in which sufficient fast breeders exist in sufficient proportion, this quantity of fission could be obtained from about 4 Mt of natural uranium which should be substantially less than that which should be ultimately available from high grade ores at around £10 per kilogram of uranium. Breeder reactors, in fact, could use uranium at a price two orders of magnitude higher, which would make available extensive low grade sources of uranium, notably the 4,000 Mt that exists in solution in the oceans. On this basis, the available fissile energy is incomparably greater than that contained in recoverable fossil fuels.

Unfortunately, the sodium-cooled fast breeder reactor on its own does not fit into the process heat strategy and would only contribute to it if the breeding gain of the fast reactors were sufficiently great to make up the breeding deficits of thermal-neutron high temperature reactors of at least equivalent energy output. (Exclusive use of sodium breeder of course would still permit the generation of hydrogen by the electrolysis route, but the installed capacity of the reactor plant would then be much higher than in the pyrolysis route.) Alternatively, a helium-cooled fast breeder reactor capable of attaining the same output temperatures would need to be developed. This is by no means out of the question.

In the absence of satisfactory fast breeders, however, a nuclear process heat strategy on a level of at least 1 Q per year could be supported with thorium cycle high temperature reactors operating in a thermal-neutral near breeding regime. These might require about 300,000 t of natural uranium and 15,000 t of thorium to yield 1 Q of heat and it would be economically feasible to use uranium from sea water in this application. To all intents and purposes this would constitute an indefinite supply of energy.

Wave power

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Solar energy is one form of income on which we can afford to live. Here is another proposal: the use of power from the waves at sea.

THE amount of power in a wave train can be estimated by calculating the change of potential energy as the water in a wave above sea level falls into the trough in front of the wave (Fig. 1). If the sea water has a density ρ , and the width of the wave front is W , then the mass of water in the half sinusoid above sea

level is

$$W\rho(\lambda/2) (H_{tc}/2\sqrt{2})$$

using the notation defined in Fig. 1. The height of the centre of gravity above sea level is

$$H_{tc}/2 \times 2\sqrt{2}$$

falling to an equal distance below. In such a situation the change of potential energy would be

$$gW\rho (\lambda/2) (H_{tc}/2\sqrt{2})^2 = W\rho gH_{tc}^2/16$$

It is known that the frequency of gravity waves in deep water is

$$(1/\lambda) (g\lambda/2\pi)^{1/2}$$

and, therefore, the rate of transfer of potential energy, or the power, is

$$W\rho gH_{tc}^2 (g\lambda)^{1/2}/16\sqrt{2}\pi \tag{1}$$

Progressive waves transport energy across the sea, and it is valid to say that the rate of transport of energy across some line is power. Power density can be specified conveniently in kW m⁻¹ of frontage.

The Institute of Oceanographic Sciences publish valuable data on waves using instruments developed by Tucker and Pierce¹. Draper and Squire² have analysed observations from Station India (59°N 19°W) which is characteristic of the western approaches to the Hebrides. The amount of power is prodigious. The relationships between various wave parameters have been explained³. For waves at sea it is more convenient to measure the period, *T*, than the wavelength, λ . Oceanographers like to use a height measurement, *H_s*, the significant wave height, defined as the average height of the highest third of the waves. In order to extend this discussion to include random waves at sea, *H_{tc}* of equation (1) can be converted to *H_s* using the root mean square displacement, *D_{rms}* : in a sinusoidal train

$$\begin{aligned} H_{tc} &= 2\sqrt{(2)}D_{rms} \\ H_s &= 4D_{rms} \text{ (ref. 3)} \\ \therefore H_{tc}^2 &= H_s^2/2 \end{aligned}$$

Wavelength, λ , can be converted to period, *T*:

$$\begin{aligned} \lambda &= T^2g/2\pi \\ \therefore \text{Power} &= W\rho g^2TH_s^2/64\pi \end{aligned} \tag{2}$$

The power which could be extracted can be predicted (Fig. 2 and ref. 2). Computer programs can apply equation (2) to each cell of Fig. 2. The average power over a whole year is 77 kW m⁻¹ of frontage. Model tests suggest that the fraction of energy which may be extracted depends on the depth of the installation.

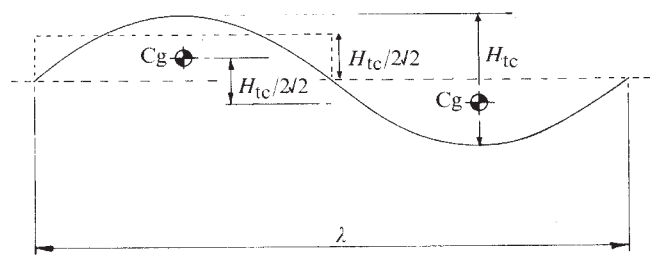


Fig. 1 Part of a progressive train of sinusoidal gravity waves in deep water. λ , wavelength; *H_{tc}*, trough to crest height; C_g, centre of gravity.

Above a depth *d*, this fraction is 1−exp (−8π²*d*/T²*g*). New arrays can be drawn up for different depths, with each cell containing the contribution down to that depth. Unfortunately, some of the power comes in uncomfortably large amounts. A practical installation might need to be underdriven or submerged during the most severe weather. Further arrays for different power limits can be constructed with the contributions of high power cells reduced to some allowable maximum. Table 1 shows the results for combined depth and power limit reduc-

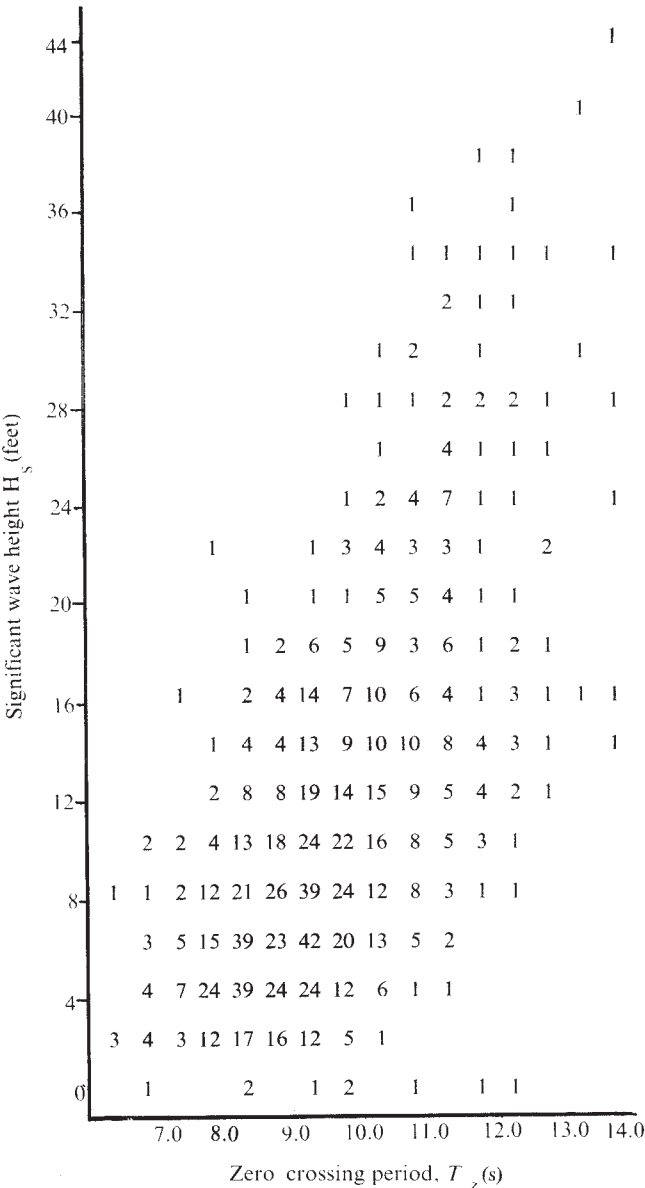


Fig. 2 Scatter diagram for whole year observations at Station India reproduced from ref. 2, showing the number of occurrences, in parts per thousand, of waves of a particular height and period.

tions from three sea areas, and Fig. 3 shows the relationship between power density and wave period for the three observing stations.

Design problems

A search of British Patents shows about a hundred proposals of varying feasibility for extracting wave energy (see refs. 4 and 5). There was a spate of them after the First World War. Flaps, floats, ramps, converging channels and liquid pistons are all advocated, and much ingenuity is expended in accommodating tidal rise and fall. Model tests on some proposals, however, show poor efficiency. More recently, though, the successful operation of equipment at low power levels for buoy and light-house use, has been described. (Y. Masuda, and T. Yoshida, preprints.)

The essential problem is finding a method to convert dispersed, random, alternating forces into concentrated, direct force, using a mechanism which is efficient at low levels and yet robust enough to withstand the worst conditions. I believe that rigid connections to the sea bed are not possible on a large scale, and that the installation must be freely floating out at sea. As much of the equipment as possible should be below the surface. Concentrations of stress must be avoided, and power should be extracted smoothly.

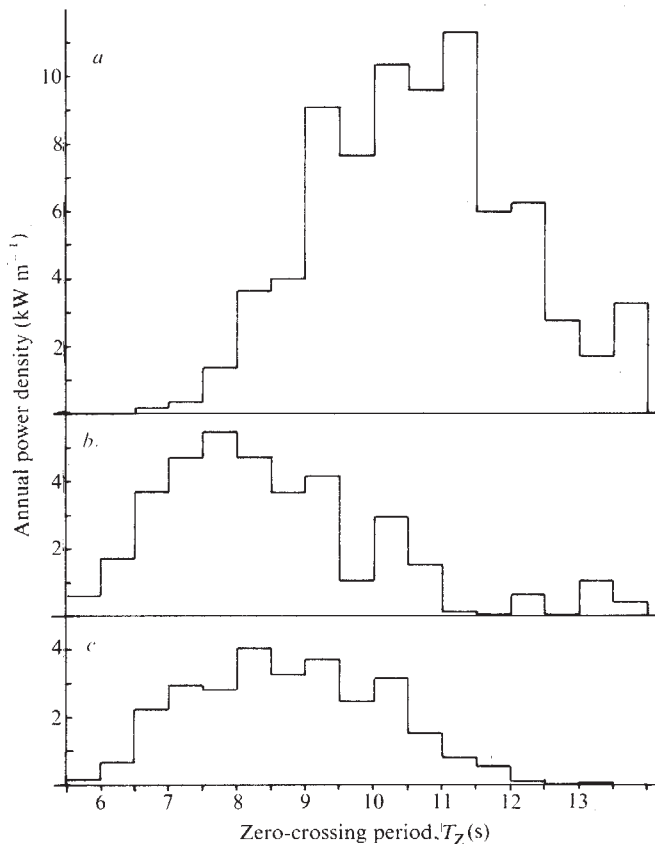


Fig. 3 Distribution of annual power density with period: *a*, Station India; *b*, MV Famita; *c*, Sevenstones.

Moving parts, are generally troublesome, but designs without them can only produce large volumes at low pressure differences, and need some kind of transformer for efficient conversion. I must, therefore, reluctantly accept the conclusion that the use of moving parts is unavoidable. I think that it is best to use rotating elements, and to protect mating surfaces from the sea. It will be difficult to gather in power from many small units moving independently, and so there should be a common framework for a number of them. As waves transmit energy to one another with very high efficiency, the water must be allowed to move in its usual circular pattern.

The first step is to get away from the idea of an object bobbing up and down, although, of course, it is this aspect of wave motion which is most apparent. Use of the to and fro movement would be much more rewarding. The energy passing through a vertical window is concentrated close to the surface and the water movements at all depths are of the same phase. I have tested a simple vertical vane pivoted about a horizontal axis along its bottom edge one eighth of a wavelength down. It works over a reasonable range of wavelengths and it shows an efficiency of about 40% when driving an electronic dynamometer. Roughly 25% of the energy is transmitted onwards, and about 20% is transmitted back to the source. It would, how-

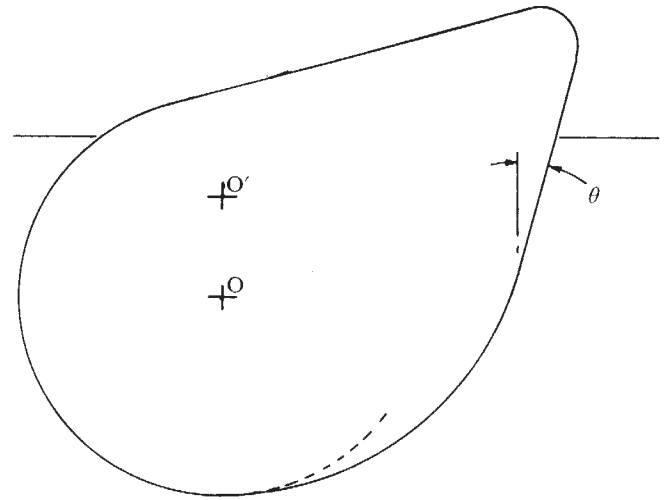


Fig. 4 An efficient vane shape designed to rotate about O. Waves come from the right.

ever, be much more efficient if, somehow, it could be designed so that it did not displace water astern and so that the amount of water displaced at any depth corresponded to the amplitudes of water movements at that depth. But is a vane of this kind possible?

The design

Consider the shape shown in section in Fig. 4. It rotates about its centre, O, and absorbs power from waves coming from the right. Its stern is a half cylinder centred at O, but from the bottom point it grows into a surface which is another cylinder centred about O'. This shape continues until it reaches an angle θ , to the vertical, at which point it develops into a tangent, which is continued above the surface. In my first model, O' is one half radius above O, and $\theta = 15^\circ$. The efficiency for wavelengths of about eight times the diameter of the small cylinder

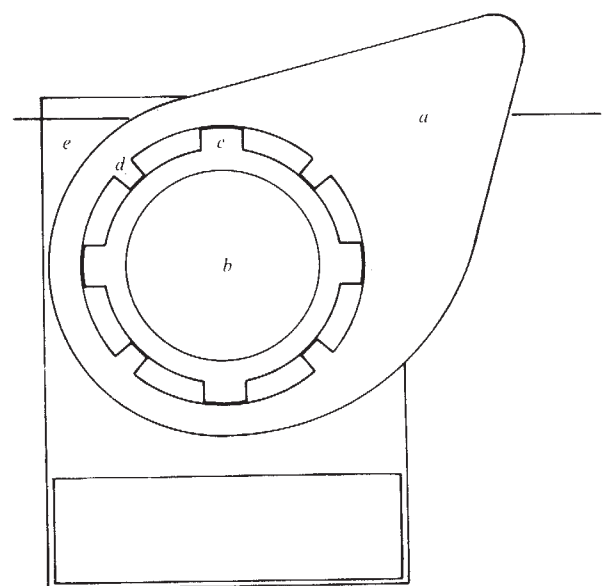


Fig. 5 A vertical section through vane and spline pump. *a*, vane; *b*, a hollow cylindrical member; *c*, paraxial ridges; *d*, inward facing ridges on the vane; *e*, vertical fin between this vane and the next. For the North Atlantic the diameter of the cylindrical portion will be between 10 and 20 m.

is over 80%. I intend to test the theory that a good vane should be able to extract nearly all of the power contained in the band of water above its depth of immersion.

When the vane moves there is no change in the displacement of the water behind it and the changing displacements in front of it rise from zero at the bottom of the cylinders to amounts close to those in the approaching wave. This means that the shape meets the necessary requirements. It is, so far, the most successful of the likely shapes that I have been testing in a wave tank. The models are coupled to a dynamometer consisting of two moving coils in a magnetic field. Velocity signals from one coil are amplified and sent to the other so as to oppose movement. Velocity and force signals are multiplied to indicate power absorbed by the vane and are compared with wave height measurements. This electronic simulation is very convenient for laboratory tests.

In full scale equipment at sea, the random rotations of a vane will produce unidirectional pulses of water flow through a special pump (Figs 5 and 6). The water is deoxygenated and decarbonated, and recirculates within the system. A vane is supported on, and rotates about a hollow cylindrical member with paraxial ridges on its surface. The outer faces of the ridges are supplied with high pressure water from an auxiliary pump, and they form hydrostatic bearings⁶. Between them there are inward facing ridges from the vane. The pair fit as a spline with close radial, but very loose circumferential clearance. The

the structure. The high pressure manifolds (400 pound inch⁻²) are made from 1 m diameter pipes (Fig. 6). Inside this ring of pipes is a large tube which forms the low pressure manifold and which returns water from the turbine to the pumps. The interstices between the pipes and the inner and outer tubes are filled with a mixture of lightweight concrete, glass fibre and resin. The ends of the pipes and tubes are swaged to allow a clamped connection of each length to the vertical fins fitted between vanes (Fig. 5). These fins house trim tanks, pressure smoothing accumulators, and the pipe work which couples each pump to the manifolds. At the bottom of the fins concrete ballast keeps the centre of gravity well below the metacentre.

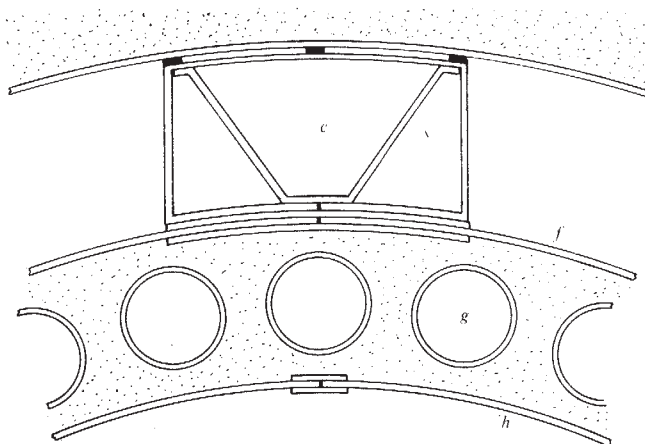


Fig. 6 Enlarged section of the spline pump, showing one ridge and the manifolds. *c*, Paraxial ridge shown in Fig. 5; *f*, outer tube containing manifolds; *g*, pipes of 1 m diameter; *h*, large tube, forming the low pressure manifold.

A crucial problem facing the designer of wave power machinery is the provision of a steady reference against which his waves can act. Many approaches use connection to the land but this design would operate out at sea. A stable reference can, however, be supplied by using a structure 0.5–1 km long. A short machine would pitch and heave and develop little force between vane and backbone. As the length is increased the installation samples a wider range of wave phases and becomes more and more steady. Stability is obtained from the inertia of the ballast weight, from the drag of the deeper parts in quieter water, and from the coupling of the machine to waves of opposing phase. The only drawback to using very great lengths is that the stress which can be developed by the worst conceivable wave rises with the square of the length. The largest predicted wave in 50 years in the North Atlantic would have a trough-to-crest height of 34 m and a period of 16.5 s. The surface particle velocity would be 6.5 m s⁻¹ with a resulting stagnation pressure of 21,000 N m⁻². The shear forces and torsions which result from such monstrous waves would not be the most serious problem. It is the bending moments which are critical, and which set limits to the lengths which can be used.

Energy storage

In common with solar, nuclear, and wind power, wave power comes at times not necessarily convenient to the user. Although its seasonal availability roughly matches demand, the problems of storage and distribution require careful attention, and will have to be taken into account in the overall planning. Electrolytic production of hydrogen from sea water looks promising in this respect.

The installations could be self propelled. They could move in

Table 1 Annual power density for different combinations of depth and power limit.

	Depth (m)	Power limit (kW m ⁻¹)		
		100	200	300
<i>a</i>	5	22.7	24.0	24.1
	7.5	29.0	32.3	33.0
	10	33.5	38.6	40.0
	15	39.1	47.0	49.8
	20	42.4	51.9	56.0
	25	44.1	55.0	59.8
<i>b</i>	5	16.4	16.5	16.5
	7.5	20.8	21.5	21.5
	10	23.8	25.1	25.1
	15	27.1	29.4	29.8
	20	28.7	31.8	32.4
	25	29.5	33.0	33.9
<i>c</i>	5	10.9	11.0	11.0
	7.5	14.2	14.5	14.5
	10	16.6	17.1	17.2
	15	19.3	20.7	20.8
	20	20.9	22.7	22.9
	25	21.8	23.9	24.2

a, Station India (59°N 19°W), total power = 77 kW m⁻¹; *b* MV Famita (57° 30'N 3°E), total power = 36.8 kW m⁻¹; *c*, Sevenstones of Lands End, total power = 25.8 kW m⁻¹.

spaces between the inward and outward facing ridges form four double acting pumps with nonreturn Macleod valves⁷ in the walls of the ridges on the cylinder (Fig. 5). These valves were originally developed for use with blood pumps. They consist of an elliptical butterfly plate across a conical passage. The centre of rotation does not pass through the centre of pressure and so there is a strong closing action. In the open state they offer minimum occlusion and are the most efficient nonreturn valves that I know of. The working surfaces of the pumps are faced with ceramic, and are ground.

A common back bone for about 40 vanes is provided by the cylindrical member. An outer tube contains manifolds connecting the spline pumps to a common turbine at the centre of

line ahead, a low drag condition, out into the Atlantic, turn abreast to the waves, and be slowly driven back by wind and wave thrust, storing hydrogen on the way. Most of the hydrogen could be discharged at a shore terminal, leaving enough to get out to sea again. This mobility gives many advantages, and obviates the mooring problem.

Wave power is clean, safe, permanent and uses relatively simple and well known technology. It is likely to receive plenty of support after a bad nuclear accident but it would be prudent to have the basic research done now⁸. We are particularly fortunate in our resources of wave energy. The approaches to the Hebrides are probably the best site in the world. A few hundred kilometres of installation could meet the total present electrical energy requirements of the UK.

I would like to thank the University of Edinburgh and the Nuffield Foundation who supplied my workshop facilities, the

National Institute of Oceanography, and my colleagues Drs O. P. Buneman, C. A. Greated, D. Mollison, and J. W. Ponton, for their help and criticism, and Sheikh Ahmed Zahi Yamani and OPEC for their continuing encouragement.

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Prospects for hydrogen as an energy resource

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Storing energy in the form of hydrogen is an attractive possibility to provide fuel for transport and the reduction of iron ore. The main obstacle is the expense of the electricity needed to synthesise hydrogen.

THE recent restrictions placed by the producing nations on the global supply of oil, and the growing realisation that world demand for oil and natural gas is increasing at a rate faster than the discovery of new resources, have focused attention on the need for alternative energy resources. There is no immediate crisis in terms of proven oil and gas reserves, but development towards alternatives should start soon if the new technology is to be widely available when it is needed. As an indication of the time scale required for the introduction of a new energy resource it is worth pointing out that 18 years after the commissioning of the first Calder Hall reactor, nuclear power has still not achieved more than 10% penetration of the market for electricity production in the United Kingdom.

Forecast of the time when the rate of production of oil will begin to decline vary over a considerable period, and might be as early as the mid-1980s if historic trends continue: it is assumed here that the decline will certainly be evident by the end of the century. As we approach that time two primary energy sources are likely to assume over-riding importance: coal and nuclear fission. But synthetic secondary fuels are likely to be needed for special purposes and hydrogen could be one of these. Hydrogen is best regarded as a potentially attractive means of storing and transporting energy which can be provided from a variety of primary sources: it is therefore more analogous to electricity than to oil, although some of its most rewarding applications may be as a substitute for oil products. The hydrogen would be produced from water and in this process more energy is expended than is recovered in burning the hydrogen subsequently; this point will, however, assume decreasing importance as the production of hydrogen moves progressively towards dependence on renewable energy resources. Hydrogen attained industrial importance a few decades ago when coal provided the primary energy for water splitting; now it is produced in larger quantities from natural gas and oil: if it is to achieve the even more widespread use implied by the 'hydrogen economy' then it will have to be

based on the energy input from nuclear fission reactors and subsequently there could be a gradual transition to nuclear fusion and solar energy resources.

Much has been written on the subject of hydrogen over the past few years, culminating in the nearly 100 papers at a recent conference devoted exclusively to the subject (see ref. 1). It is not possible to review all of this work here; I shall attempt rather to take a realistic view of the overall prospects and of some of the problems to be overcome.

Markets for hydrogen

As oil becomes a scarce resource and nuclear energy takes over, in principle all major energy users except air transport could be satisfied by the increased availability of relatively cheap electricity—much has been written on the advent of the all-electric economy. This would also require however, the development of major new technology, of which the long range electric road vehicle is perhaps an outstanding example. It is possible that when the costs of transmission and storage are added to the cost of production, under some circumstances hydrogen may become competitive with electricity for many uses. This possibility of interchange and substitution between several energy sources renders the whole subject very complex: the forecaster finds it fascinating and yet extremely hazardous.

One of the largest new uses for hydrogen could be as a fuel for road transport: in the United Kingdom this might ultimately amount to a requirement of several million tons per year. The competition will however be strong among several candidate fuel supplies:

- allocate oil to road transport as a priority item
- electricity, based on advanced batteries for energy storage on the vehicle
- liquified methane (natural or substitute)
- methanol
- hydrogen

Each of these possibilities has its advocates and, apart from the first item, each has a considerable range of development problems to be overcome. Perhaps a mixture of several solutions is the most likely outcome, with each fuel taking a particular share of the total market.

Practical experience has shown that the use of hydrogen requires little alteration to the internal combustion engine on

which so much development effort has already been lavished, and the environmental pollution from hydrogen would be much less than from petrol. It is feasible for the same vehicle to be engineered to be able to switch as required between a hydrogen and a hydrocarbon fuel supply. Increasing attention is now being given to devising the best means of storage of hydrogen on road vehicles. Storage as gas would be totally uneconomic but on present evidence there is no clear choice between cryogenic techniques and storage in metal hydrides. It is possible that hydrides will prove to have over-riding safety advantages. The most promising hydride system proposed so far is based on iron-titanium alloys, which are capable of absorbing and desorbing hydrogen at near ambient temperatures. There is much useful basic work to be done to arrive at the optimum hydride composition to meet criteria of high hydrogen density, low overall mass, avoidance of high operating temperatures, and the ability to withstand multiple recycles.

Economic forces will play a large part in determining whether hydrogen really can compete. There is a growing number of attempts in the literature to forecast the relative costs of the various fuels up to the end of the century, and as would be expected they cover a considerable range. For the United Kingdom in the late 1990s, the ranges in Table 1 summarise the production cost estimates. North American cost predictions tend to be a little lower, mainly in the range 100–140 (see ref. 2 for a useful comparative summary) pence per GJ for hydrogen by electrolysis. It is apparent from these figures that there would be a chance for hydrogen to become competitive with petrol towards the end of the century if the more optimistic rather than pessimistic assumptions prevail. Synthetic petrol from coal seems somewhat more promising but, as pointed out by G. V. Day at a conference on energy, Europe and the 1980s at the Institute of Electrical Engineers, London, May 1974, environmental restrictions and the availability of labour may restrict coal output to below the level required for the large-scale synthesis of petrol in addition to coal's more traditional role in electricity production.

There is potentially a much larger market for hydrogen as a substitute for natural gas for the majority of domestic and industrial purposes (possibly as high as 12×10^6 tons yr^{-1} in the United Kingdom) in which its energy content rather than chemical properties are important. As long as supplies remain available from the North Sea it will perhaps be impossible for hydrogen to compete on cost grounds (a factor of two to three lower than the cost quoted in Table 1 would be needed). But again towards the end of the century, these supplies may well become insufficient and hydrogen could present competition to replacement by substitute natural gas (SNG) from coal. Though at first sight it might seem possible to utilise the existing gas distribution system to distribute hydrogen, there may be very substantial problems in technology and in the logistics of a gradual changeover. Although this market is very large, therefore, it might not prove possible to penetrate it, except in the case of communities isolated from the national gas grid system. Detailed assessment studies of this aspect of the hydrogen economy are required.

There are specialised uses for hydrogen which may account

for somewhat smaller demands, but which nevertheless would be large by current standards of production. One of these is the direct reduction of iron ore for steel making. This idea has been around for a long time and is currently attracting more attention because of problems created by the diminishing supply of metallurgical coke. In the United Kingdom the hydrogen demand could rise to the order of 10^6 tons yr^{-1} for this purpose. Second, imaginative designers of aircraft have also been proposing hydrogen as a substitute for aviation hydrocarbon fuel. Modern jet aircraft have voracious appetites for fuel: an average passenger in a plane with a load factor of 50% 'consumes' four times his own weight of fuel on a transatlantic crossing. Though it could be argued that this should be a priority outlet for oil products, some observers have claimed that there could be real technological advantages for hydrogen in aircraft use. Several preliminary design studies have been made of aircraft fuelled by hydrogen for both very high speed applications (Mach 5–6) and subsonic jumbo jets, but it is evident that much ingenuity will be required to avoid the very considerable advantage of low fuel weight per unit of stored energy being cancelled by problems arising from the high volumetric requirements for storage. If these design problems could be overcome, this could be an ideal use for hydrogen in transport, because fuel handling would be under strict control.

Finally, there is a hybrid fuel economy situation in which nuclear-based hydrogen could be used to adjust the C:H ratio of fossil fuels, as in the production of substitute oil or gas from coal.

Outlined above have been several contenders for the most likely new outlets for hydrogen if it can be produced more cheaply than at present and in much larger quantities. Assuming that the most feasible primary energy source for producing the hydrogen from water is the nuclear fission reactor and that the only feasible method on present evidence is by electrolysis using the nuclear-produced electricity (see below), it is of interest to consider the size of nuclear installation that might be required (Table 2). The number of reactors of the 1,000 MW

Table 2 Approximate number of 1,000 MW reactors to serve various potential UK markets for hydrogen produced by electrolysis

	No. of reactors
One million cars	3
Iron ore reduction (based on 1971 output level)	7
Fleet of 10 supersonic long-range aircraft	2

class, currently a reasonably standard size for design and construction purposes, would be relatively small to meet United Kingdom needs compared with the likely installed capacity for electricity production by the end of the century.

Methods of production

The outlets discussed above lie in the range 10^5 – 10^7 tons yr^{-1} : at the upper end these are large by present day standards for any single country. Two processes are regarded as competitors to make the best use of nuclear energy for the decomposition of water. The energy could either be used directly as high temperature heat to promote thermochemical decomposition, or the nuclear energy could be converted into electricity and used in an electrolysis plant.

Although the electrolytic route introduces the additional step of electricity production with an immediate loss of up to two thirds of the original energy, it is often regarded as the reference process. A large development programme would be needed, however, to translate current practice into a successful and economic plant of the size required.

Several authors have demonstrated that the major component in the cost of hydrogen from large plants would be the price of the electricity. In order to minimise the latter, the advantages

Table 1 End-of-century fuel production costs in United Kingdom

	pence per GJ
Petrol (tax free) from crude oil*	140–220
Petrol from coal†‡	110–130
Hydrogen by electrolysis† (advanced technology)	135–175

* A range of double to treble the early 1973 costs is assumed.

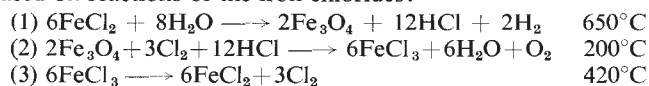
† Extrapolated from a paper presented by G. V. Day at a Conference on Energy, Europe and the 1980s, at the Institute of Electrical Engineers, London, May 1974.

‡ Extrapolated from a paper by J. S. Harrison to the Management Group of the Society of Chemical Industry, November 1973. Coal assumed to cost double 1973 prices.

of scale would need to be realised and nuclear stations producing about 1,000 MW are envisaged directly coupled to the electrolysis plants. Each 1,000 MW complex should be capable of producing about 150,000 tons yr^{-1} of hydrogen. This is about 70 times the size of the largest unit yet built, and a very much larger extrapolation from the average electrolytic plant.

The problems of such very large plants have not yet been fully assessed. It is already clear, however, that conventional electrolyzers in which virtually all the industrial know-how at present resides will not operate at a sufficiently high energy efficiency to render them economically viable. It would be necessary, therefore, to develop new types of cell probably incorporating porous electrodes and operating at high pressures. One of the most interesting new concepts in this field is the solid polymer electrolyte cell described by L. J. Nuttall, A. P. Fickett, and N. A. Titterton at the conference on hydrogen economy, University of Miami, March, 1974. This cell has been developed primarily as a means of producing oxygen for aerospace and submarine applications, but it is claimed that it can be adapted readily for large-scale hydrogen production. The electrolyte is a solid plastic sheet of perfluorinated sulphonic acid polymer which is a good conductor of hydrogen ions, and the cells can be constructed in such a manner as to produce hydrogen directly at high pressures, thereby avoiding extra compression costs which might otherwise be incurred in optimum transport and use.

An alternative to electrolysis which is stimulating rapidly growing interest is the decomposition of water by closed-cycle thermochemical processes. At least 10 research centres are now actively interested in this possibility and over thirty potential cycles have appeared in the published papers. The prize is a higher energy efficiency than is possible in the electrolytic route, perhaps approaching a factor of two higher under favourable circumstances. It is disappointing that none of the cycles described so far is an outright winner. The most substantial programme on thermochemical cycles is that at the Ispra laboratory of the Euratom Joint Research Centre. An illustrative example of the range of cycles which they have proposed is based on reactions of the iron chlorides:



Insufficient experimental information is yet available on these reactions for a conclusion to be reached concerning the cycle's chance of technical success. As with all other proposed cycles, certain difficulties can be foreseen already: reaction 1 needs close control of temperature to avoid a path to different products, reaction 3 presents chemical engineering problems arising from the volatility of FeCl_3 . Important constraints which can rule out some otherwise promising cycles are imposed by the upper limit of temperature which can be provided by a

nuclear reactor system (because of limitations on materials performance in heat exchangers), the economic need to avoid exotic materials of construction (difficult when handling metallic halides at high temperatures), the requirement for high rates of reaction to cut down the size of the plant items and the need to avoid the recycling movement of massive amounts of solid materials in the plant.

Electrolysis will allow the earlier introduction of large scale hydrogen production if other factors are favourable, but if a more promising thermochemical cycle can be devised this route could take over in the longer term. There is insufficient information available at present for the thermochemical route to be costed.

Conclusions

Despite growing current interest, the widespread introduction of hydrogen as an energy carrier is still well in the future. But such economic forecasts as can be made on rather scant evidence do not rule out the possibility that hydrogen could be competitive with alternatives such as petrol from oil or coal, or nuclear-produced electricity, by the end of the century. These estimates are based on the production of hydrogen by electrolysis, but if a thermochemical route emerges from the substantial research programmes now being carried out, it would have the potential of considerably improving the prospects.

The safety aspects of the widespread use of hydrogen require close examination, but in principle no major stumbling block is likely to emerge. The introduction of hydrogen could, however, best take place in the controlled environments represented by aircraft and commercial road transport fleets, and industrial plants for the hydrogenation of coal or the direct reduction of iron ore. Use in the private motor car and as a general substitute for natural gas seem further off.

Above all, the advent of the hydrogen economy must depend upon the successful further development of nuclear power to provide the cheap reliable primary energy source for water splitting. The electrolytic route can be linked to the need for successful development of the sodium cooled fast reactor to provide the cheapest electricity in the long-term, whereas the thermochemical route needs a fully developed high-temperature reactor system to provide the high temperatures required.

Both routes to hydrogen would require a large development programme, with the thermochemical route currently lagging because a universally agreed attractive cycle has not yet been devised. At the basic scientific level the thermochemical route presents an immensely stimulating challenge to chemists, chemical engineers and materials scientists.

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Solar energy

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Studies have been made of a very wide range of possible ways in which solar energy might be used for domestic and industrial purposes. Some are already economically viable and the prospects for others are improving through intensive programmes of research and development.

MAN has been using solar energy purposefully for millennia and will continue to do so, since it is the driving force for agriculture. In the pre-industrial era, it was the predominant source of power also, for the windmills, watermills and sailing ships of the time derived their energy ultimately from the sun. These devices could not have driven the subsequent period of industrial expansion because, without growing to inordinate size, they could not have made available generally powers greater than a

few hundred kW. They were well suited to modest local needs, but could not serve the demands of industry, concentrated in the interests of high productivity. This became possible only with the use of the concentrated solar energy stored in the fossil fuels. Yet we may shortly have to return to an economy directly powered by solar energy as the brief era of cheap fuel comes to its inevitable end. In the long term we have no choice; solar energy is the only perpetual source capable of meeting the likely demands of the future. We have some options in the short term. The fission reactor could support us for a time and will certainly ease the problems of diminishing fossil fuels, though it is not universally welcomed and a shortage of fissionable fuel is already envisaged. A fusion reactor would presumably defer a general energy shortage for a very long period, but it is proving elusive. It might be sensible to enquire whether the resources allocated to fusion research could be more profitably applied to the exploitation of solar energy.

Available energy

The decline of the windmill and watermill is traceable to the low energy flows available to any given machine. Though the total energy arriving from the sun is immense, the flux is very small by present-day engineering standards. At the top of the atmosphere the maximum value is about 1.3 kW m^{-2} , but a variety of scattering and absorbing processes reduce this to about 0.9 kW m^{-2} at the surface. The difficulties of effective utilisation are increased by the seasonal and hourly variations, which are functions of latitude, and by the random fluctuations due to the weather. In summer,

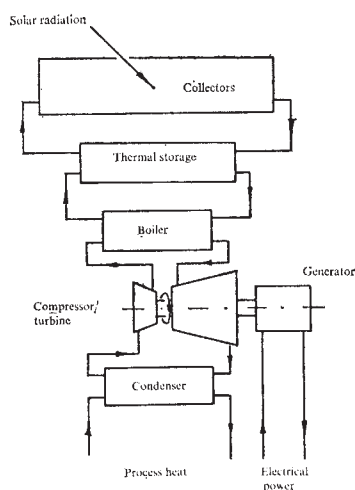


Fig. 1 Elements of thermal energy conversion system.

the increasing day length with increasing latitude helps to compensate for the longer air path so that in clear conditions the total energy received during one day varies only weakly with latitude. The winter isolation, on the other hand, is much affected by latitude; in Britain, for instance (latitude about 52°), a clear day in midwinter yields only about one-tenth of the energy of one in midsummer.

The total annual insolation (energy incident on a horizontal surface) is around 1.5 MW h m^{-2} over large areas of the earth and in places it exceeds 2 MW h m^{-2} .

The effects of climate, though substantial, are less than is usually supposed. The average annual insolation in Britain, with its notorious cloud cover, is nearly 1 MW h m^{-2} . Britons are usually surprised to learn that, on average, the United Kingdom receives more than half the energy available in Australia or two-thirds of that in the United States. The large droplet sizes of cloud in relation to the wavelength of the radiation causes predominantly forward-scattering, so that a sizeable fraction penetrates unless the

cloud is optically very deep. At the same time, the radiation becomes diffused. Due to the high cloud cover in Britain an unusually high proportion—more than half—of the radiation reaching the surface there is diffused. This is important because this part of the radiation cannot be brought to a focus.

Large scale use

The entire world energy demand for human purposes other than agriculture is less than the solar energy falling on a region 100 km square in a favourable location. This is a trifling area compared with that of the world's land surface or even of the deserts, but it is very large on the scale of human constructions. Inefficiencies in the energy conversion processes used would mean that even greater collecting areas would be needed. Nevertheless, serious study has been given to the design of 'solar farms' thousands of square kilometres in extent¹. In these, the collectors concentrate the radiation so as to produce in a working fluid a temperature high enough to operate a

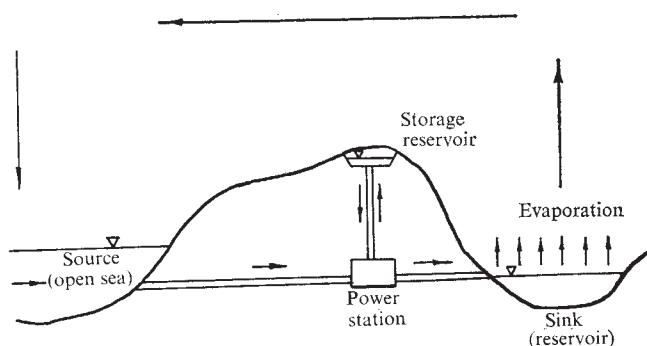


Fig. 2 Heliohydroelectric scheme, with pumped storage.

thermodynamic engine with respectable efficiency. An intermediate fluid might be used to link the collectors to a thermal storage element which permits a match to be obtained between the energy supply and the demand (Fig. 1). The cost of collectors is a significant factor in all uses of solar energy. When they are of the concentrating type, they need to be robust to maintain good fidelity of shape and resistance to wind forces and they must be steerable to follow the apparent motion of the sun. Useful temperatures can be obtained from two-dimensional parabolic troughs with the focal line orientated east-west, requiring only a slow seasonal adjustment to follow the sun's declination. It might be foreseen that these could be mass-produced in modules of moderate size which could in principle be indefinitely replicated to build up a large station.

The cheapest large scale collectors, in terms of cost per unit area, are reservoirs. A scheme recently advanced on this basis involves the Qattara Depression in the Libyan Desert². It is proposed that this region should be connected to the Mediterranean, about 80 km away. The high evaporation rate, about 1.7 m a year, would maintain a free water surface $12,000 \text{ km}^2$ in area within the Depression at about 60 m below sea level. This would be sufficient to operate a hydroelectric plant of about $4,000 \text{ MW}$ capacity, as shown in Fig. 2.

The ultimate in large collectors is the sea itself. Power plant exploiting the temperature gradient in ocean waters was first constructed in 1930³ and the possibilities have been re-assessed more recently. Though the small temperature differences available inevitably mean low thermodynamic efficiency, the economics are by no means unfavourable⁴.

Large scale systems such as these effectively combine the functions of collection and storage. A corresponding

arrangement on land might make use of the photosynthetic manufacture of combustible hydrocarbons. There is already a world shortage of timber and presumably of land suitable for traditional afforestation, but official studies in the United States⁵ and Australia⁶ both comment on the relatively small fraction of land area which would be needed for the intensive cultivation of fast-growing plants capable of furnishing a significant proportion of the energy demand. It is to be noted, however, that studies have yet to be made of the engineering problems of harvesting, transport and processing involved in such a scheme. These studies are urgently needed, since photosynthesis offers the most direct path to the manufacture of liquid and gaseous fuels which will probably continue to be needed indefinitely for transport.

A major objection to all schemes for the conversion of solar energy on a large scale at central stations is that there is very little freedom of choice on where they might be sited. Nearly always, they will have to be distant from the places in which the energy is to be used. This not only requires expensive distribution networks of power lines or gas pipelines, but raises the possibility of undesirable climatic effects arising from the transfer of energy on a large scale away from the places at which it has hitherto been absorbed. These and other factors have led many to the view that the proper scale of solar energy conversion is local rather than central. As this is a reversion to its pre-industrial use, it follows that some attention will be necessary to the methods of integrating such a source with the others that will be available, particularly in urban-industrial societies.

But, throughout the world, there is a huge potential requirement for devices with capacities ranging from a few watts to a few tens of kilowatts. About 80% of the Earth's population lives between the 40° parallels, including many of the poorest, but they can nearly all count on an energy flux exceeding $1 \text{ MW h m}^{-2} \text{ yr}^{-1}$. It is more instructive to compare this, not with the million MW h per year required from a European power station, but with the level of local demand: the 1 MW h yr^{-1} of work performed by a pair of bullocks, or the 100 kW h needed to winnow the grain from a family's land. All the hot-water needs of a clinic and the refrigeration of its wards and theatres could be provided by the energy which falls on its roofs. The roof of a dwelling could furnish power for a loom or lathe; that of a barn enough for a pump, able to irrigate 10 hectares of land. A school's radio and television receivers could be powered by a device the size of a blackboard; a solar still the size of a duck pond could yield enough drinking water for a village.

Power for small local enterprises like these cannot be provided economically by large-scale generation at central sites, even by conventional means, largely because of the high cost of transmission where the population density is low. The cost of fuels for local power plant is also greatly inflated by distance, doubling in a few hundred km over land. It is being recognised that rural communities must be given more stability and, for this, work and amenity must be provided within the village. Solar-powered devices could substantially raise productivity in such local enterprises as weaving, timber sawing, paper milling, food processing and preserving, light manufacturing, plant maintenance, irrigation, fresh water supply, drainage and a host of other activities. By these devices, it may yet be possible to revitalise the village from within.

Local use

The conversion of solar energy for modest local demands has been the subject of experimental investigation for many years. It is known that solar stills, solar-powered engines and other devices were successfully operated a century ago. But they were unable to compete economically

in an era of cheap fuel and their credibility suffered through the unguarded optimism of enthusiastic advocates whose claims were easily discredited. More recently, these devices have begun to receive sober engineering and economic analysis, exemplified by the contents of two specialist journals devoted to the subject: *Solar Energy* (Pergamon Press) and *Geliotekhnika* (available in translation as *Applied Solar Energy* (Allerton Press)).

Quite thorough studies have now been made of ways in which solar energy might be used on a local scale^{7,8}. These include its direct use for heating and cooking; driving a thermodynamic system, as in distillation, desalination, air conditioning, crop drying and so on; providing a source for heat engines, refrigerators and heat pumps; direct conversion to electricity using thermionic, thermoelectric and photoelectric generators; and the promotion of photochemical and photobiological processes leading to the generation of electricity or the production of liquid and gaseous fuels and other chemical products. Some of these processes are already economically competitive and their position is bound to improve as fuels become scarcer and dearer.

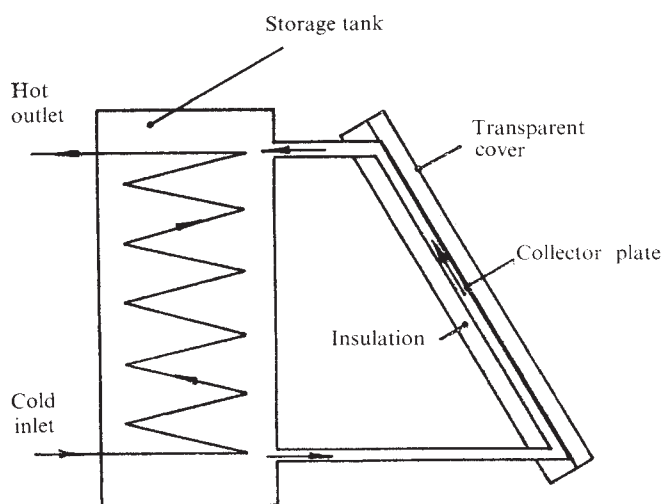


Fig. 3 Solar collector for domestic hot water system.

Flat-plate water heaters, of the kind illustrated in Fig. 3, are already widely used in many parts of the world and are now being marketed by several manufacturers in Britain. Up to about 60% of the incident energy can be transmitted to the water at useful temperatures (40–50° C) if the re-radiation is minimised by the use of glass cover plates, in the manner of a greenhouse, and of selective coatings on the absorbing surface which combine good absorptivity for solar radiation with low emissivity at working temperature. Heaters of this kind already make significant contributions to energy supplies for domestic, commercial and industrial purposes and their use is certain to grow⁶. Usually, they are linked with conventional heating systems and act as fuel savers rather than being designed to meet the entire heating load. It is estimated that in Britain they could yield about $10^6 \text{ MW h yr}^{-1}$ for each 1% of dwellings equipped with them⁹. Much work is in hand worldwide to obtain a significant contribution to space heating and air conditioning from solar energy, and the design of buildings to exploit this is becoming a major preoccupation of architects. There is a history of building experimental 'solar houses' extending over some decades, in which Britain has had its share. In these, there has to be a means of energy storage to accommodate the seasonal and daily

variation in the energy available, and the fluctuations due to the weather. Thermal storage is obtained by changes in the sensible heat of a reservoir, which may be liquid or solid, or by latent heat exchange during a change of phase of the storage medium. Optimisation studies show that it is economical to obtain from the sun a significant fraction—typically $\frac{1}{3}$ to $\frac{1}{2}$ —of the heating requirements of ordinary dwelling houses, even at quite high latitudes¹⁰. A typical domestic arrangement is shown in Fig. 4.

The economical provision of mechanical work and electricity on a small scale is proving elusive. There is little to choose in capital cost between low temperature heat engines driven by flat-plate collectors and more efficient ones with concentrating collectors. Both are still much more expensive than other sources such as the small diesel engine. But there are places where fuel costs are unusually high due to transport charges, where the net cost of work from solar engines would be competitive. These should be simple and robust and capable of being built using local resources. Their adoption will demand more from the entrepreneur than the engineer now.

On the other hand, much technical work remains to be done on direct conversion to electricity. Devices such as thermionic and thermoelectric generators require the maintenance of a temperature difference for their operation and hence have a restricted efficiency for thermodynamic reasons. Thermionic generators can operate effectively only with a high cathode temperature, perhaps of the order of 1,500 K, and this implies the use of concentrators of good optical quality, capable of tracking the sun accurately. This and other technical features have caused the thermionic generator to fall into disfavour for solar energy conversion, though it is capable in principle of quite good overall efficiency. Thermoelectric generators are subject to certain material limitations as well as thermodynamic ones, but continue to be of interest, even for use with flat-plate collectors, because of their simplicity. Photovoltaic cells, developed primarily for use in spacecraft, have reached useful conversion efficiencies—about 15% in full sunlight. Some, such as the GaAs/GaAlAs cells, function well in highly concentrated light. But these are single-crystal cells produced by very expensive processes. At a capital cost of some £10 to £100 per W of installed capacity, their use can so far be justified only in very specialised applications such as the powering of active buoys and other remote navigational aids and radio stations. Strenuous efforts are in hand to reduce the cost of photocells. This might be done by the development of large scale methods of production, perhaps of silicon ribbon which retains a single-crystal structure¹¹ or of thin-film polycrystalline cells. If capital costs are sufficiently low, quite small conversion efficiencies may be acceptable—the 8% reported for CdS/Cu₂S heterojunction cells¹², for example.

Outlook

It seems certain that non-agricultural uses of solar energy will continue to increase throughout the world, as the fossil fuels become scarcer and dearer. Already solar water heating is competitive in many countries and solar space heating seems about to become so. The outlook for conversion into work and electricity in the near future seems promising but is less certain. The principles are well established, and many devices have been built and tested in prototype form, but much more work remains to be done before they can have an assured place in the energy economy.

There is every sign that the necessary research and development work related to effective solar energy utilisation will be carried out promptly, at least as far as the needs of the developed countries are concerned. A US National Science Foundation report of 1972³ recommended a commitment of \$3,500 million in this area, justifying this with

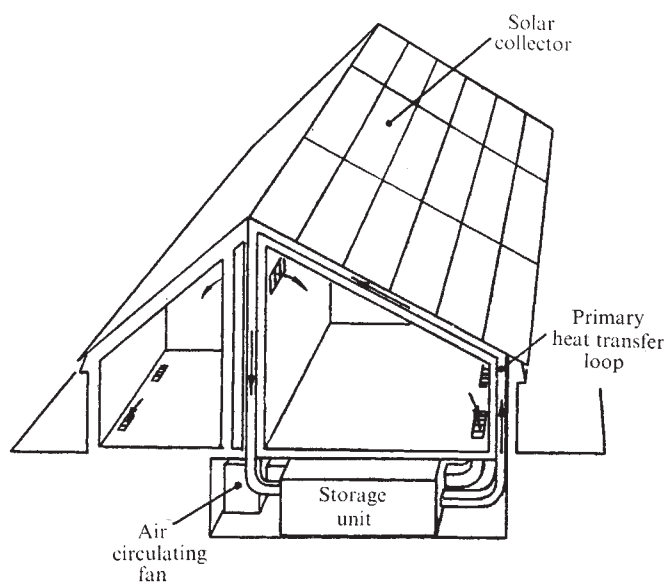


Fig. 4 Solar space heating system.

the contention that solar energy could provide 35% of the nation's heating and cooling requirements for buildings, 30% of its gaseous fuels, 10% of its liquid fuels and 20% of its electricity. These recommendations are being pressed ahead with extraordinary vigour; already the annual research budget for solar energy work has reached about \$15 million. A somewhat similar programme, though not yet funded, was recommended by the Australian Academy of Sciences last year⁶. This suggests that solar energy could provide 40% of Australia's low grade heat and 50% of her liquid fuel within 25 years. The Soviet Union has maintained several centres for solar energy research for many years. Japan, long known for its widespread use of solar water heaters, is planning a major new solar energy programme said to be comparable with the American one.

There seems to have been little official support in western Europe though there has been some activity in the universities and the interest of industry is awakening. It remains to be seen whether this work will benefit the under-developed countries, which in many ways, are in most need of it. They usually have little indigenous fuel and are severely affected by rising fuel costs. On the other hand, they generally have ample solar energy, with little seasonal variation and a population which is still largely dispersed (but is drifting to the towns at an alarming rate). The encouragement of a greater use of solar energy in these countries could be the most sensible and effective way of giving financial and technical aid.

¹ Meinel, A. B., and Meinel, M. P., *Physics Today*, **25**, 44–50 (February 1972).

² Bassler, F., *Sol. Energy*, **14**, 21–28 (1972).

³ Claude, G., *Mech. Engng.*, **52**, 1039–1044 (1930).

⁴ Anderson, J. H., and Anderson, J. H., jun., *Mech. Engng.*, **89**, 41–46 (1966).

⁵ *An assessment of solar energy as a national energy resource* (Nat. Sci. Foundation NSF RA/N-73-001, University of Maryland, 1972).

⁶ *Aust. Acad. Sci. Report 17*, (Griffin Press, Netley, South Australia, September 1973).

⁷ Daniels, F., *Direct Use of the Sun's Energy* (Yale University Press, New Haven, 1964).

⁸ Brinkworth, B. J., *Solar Energy for Man* (Compton Press, Salisbury, 1972).

⁹ Brinkworth, B. J., *Electronics and Power*, **20**, 356–359 (1974).

¹⁰ Lorsch, H. G., *Energy Conversion*, **13**, 1–5 (1973).

¹¹ Currin, C. G., *Proc. 9th IEEE Photovoltaic Specialists Conf.* John Hopkins Univ., May 1972. (Institute of Electrical and Electronics Engineers).

¹² Coste, G., in *Solar Cells* (edit. by Gordon and Breach, New York, 1971).

Tidal energy from the Severn Estuary

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Energy generation from the tides is widely regarded as economically less viable than that from conventional thermal alternatives. Although economic comparisons are unfavourable the potential overall improvements in network operation indicate the true value of new plant.

In operation, a tidal power scheme could possess much of the flexibility of highly versatile, conventional hydroelectric stations, and many types of project have been suggested. To assess in 1974 the preferred style of operation (not only for a tidal scheme but also for new thermal plant) necessitates anticipating consumer and generating demands beyond 1984, for it will not be until then, and for a long time afterwards, that any scheme planned now, whether tidal or otherwise, would be working. In particular, after 1984 a substantial nuclear component will emerge in the generating structure of all those industrial countries which opt for thermal energy schemes (few are even now able to rely on further conventional hydroelectric sources, and stations which require fossil fuels are unlikely to be favoured in large numbers). Coupled with the present crises in the provision of fossil fuels, and the complementary gross escalation of their costs, it is no surprise to find that the status of tidal power has, psychologically at least, improved markedly.

The last detailed, government-sponsored study of tidal energy in the UK was concluded in 1945; it was prompted by the additional power requirements of the war effort, and it leaned heavily on the results of the only major UK study, of the Severn Estuary, which was completed in 1933. The schemes anticipated at that time were on a relatively small scale. A favoured site for the barrage was well up the estuary at English Stones, just below the present Severn Road Bridge (Fig. 1). The maximum power output would have been about 800 MW, over 10% of the maximum demand during the 1940s.

Canada, France and the USSR have since been studying more actively their own potential for tidal energy generation. The best site in the World, however, is probably the Severn Estuary. The Severn is not excessively deep or wide, the tides are almost the highest occurring anywhere, and it is near to centres which require a high energy load. But despite these advantages, which have been appreciated ever since the first studies, it is now more necessary to give close consideration to ecological factors than it was 30 years ago. Harnessing tidal energy must be seen to be not only economically and functionally competitive with other forms of generation but, in addition, must be environmentally acceptable in its own right. After all, the crisis in fuels is not so serious that all other considerations have to be overlooked, and in any case even the Severn Estuary-Bristol Channel could not provide more than about 25% of the present peak total demand for electricity, a ratio which will have declined considerably by 1984.

Energy potential of the tides

The rhythm of tidal variation from place to place, and from time to time at any place is well known. A few sites,

like the Severn Estuary, the Bay of Fundy (Canada) and the Ile de Chausey (France) have exceptional spring tidal ranges of 14–15 m; and the range is over 16 m in Ungava Bay (Canada). These particularly high ranges only occur locally within each embayment, as a result of both focusing effects and a measure of resonance between the tidal and natural frequencies of oscillating water within the boundary of the estuary. Progressively lower maximum tides occur away from the optimum positions.

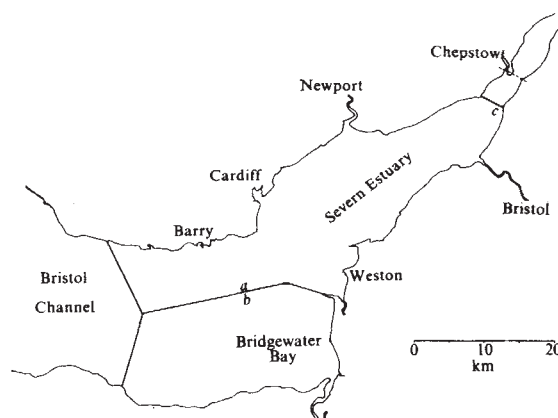


Fig. 1 Outline map of the Severn Estuary and Bristol Channel, showing the barrage scheme proposed by Martin in 1945. a, High level basin; b, low level basin; c, 1933/45 barrage proposals.

Much less favourable circumstances for energy generation apply during neap tides, when the range is typically about one half of that during spring tides. Inequality between the lunar and solar periods is responsible for this spring-neap-spring cycle, which takes nearly 15 days; it also gives rise to a tidal period of 12.4 h. Generation is therefore not possible over more than about 4 h during both the ebb and flood tide phases (Fig. 2), and the amount of energy, as well as the times at which it becomes available, vary from day to day. Nearly half of the output will coincide with off-peak times (peak demands for electricity now extend up to 14 h, from 0800–2200h).

Although, compared with generation from solar, wave and wind sources, the tides could be regarded as a relatively predictable form of natural energy, the form of output is still inadequate for electrical networks which depend heavily on thermal plant to meet a fairly predictable daily pattern of demand. To incorporate tidal energy into these networks an equivalent amount of thermal plant would have to stand by to carry the load when the state of the tide was not suitable for generation. This extra plant would have to be provided and run at low thermal efficiency (because duty periods are short), whereas continuous operation without the tidal scheme would produce the same output at a much improved efficiency.

Regularised output from a tidal scheme

The various limitations of the tides, quite apart from economical factors, have been a considerable barrier to

commercial development during this century. Earlier (tide mills can be traced back to 1180, at Dover), the consequences were accepted only in the absence of more reasonable alternatives. But methods of improving the regularity of output have been proposed, although they involve extra costs and energy losses:

- Power could be transmitted as and when available, either to the consumer by day or to a pump storage station. The latter alternative involves two reservoirs at differing elevations, interconnected through pump turbines. Many such installations now exist, storing energy from thermal power stations at night, for daytime release to meet short term peak load and emergency conditions. Over 75% storage efficiency can be achieved, so that six hours of pumping gives about four and a half hours generation at the same rate, when required. This technique was favoured in the 1933 and 1945 Reports. With tidal power, however, the additional costs fail to overcome the basic economic objections to tidal energy production.

- Two basins could be constructed in the estuary, each filled and drained when the tide is high and low respectively; energy would be generated by flow between the basins. This alternative was adapted by C. A. Martin (unpublished) for the Severn Estuary in 1945 (Fig. 1). Continuous output thus becomes possible; in Martin's scheme it varied between 3,350 and 850 MW. Unfortunately, however, publication of this imaginative scheme coincided with a slump in energy demand, and in any case it was ahead of its time in terms of the size of plant needed to provide for the normal annual growth rate in demand of that period.

Other schemes resembling that of Martin have followed as the scale of the second era of barrage planning has become more commensurate with requirements. For economical reasons, large thermal installations have also become fashionable: new stations, including nuclear plant, are, or soon will be, about 2,000 MW (in a 50,000 MW network). This trend is likely to persist as the nuclear proportion of the total installed capacity escalates towards 50% by the end of this century. After 1990 the nuclear energy component will therefore be greater in magnitude than the normal night time demand (equal to about 40% of the daytime demand). When this happens, all plant which use fossil fuels will have to be operated only during the daytime if nuclear stations are to be run continuously. Thereafter, the operation of nuclear stations would have to become flexible, involving not only further development and capital costs, but also a drop in the operating efficiency and extra fuel costs. This cannot be avoided unless excess energy is either discharged to the environment in the form of heat, or is supplied to pumped storage facilities.

I have already mentioned the fact that the use of pumped storage facilities allows energy to be regenerated as required, although bulk energy transfer from night to day should be distributed uniformly over the 12–14 h demand period if equivalent thermal plant (that is, the older, smaller and more uneconomic stations) are to be displaced entirely from the system. Given that pumped storage could be operated in this way, that is, in addition to the present duty of meeting relatively small variations in demand, there could well be merits in adopting it before a 'nuclear excess' situation arises. That would allow many of the more efficient fossil-fuelled stations which would otherwise have to be shut down at night, to be run continuously with an improved efficiency. In the limit, the ideal situation (which is not unobtainable in this case) would be to run all thermal plant, equivalent in capacity to about 75% of the maximum demand, on a continuous basis, and carry over from night to day accordingly.

The major objections to pumped storage installations are probably environmental. Creating reservoirs for any purpose receives little spontaneous sympathy from the community at large, especially when these cannot be made available for recreational purposes. Recently, the Central Electricity

Generating Board (England and Wales) has experienced strong opposition to these projects; their new Dinorwic scheme in the Snowdon National Park in North Wales is regarded by amenity groups as aesthetically and environmentally unacceptable, because, they claim, it will spoil famous landscapes, and introduce extensive 'tide mark' scars as the water level changes more than 100 feet in four hours (three times the rate of rise and fall of the remarkable Severn Estuary tides).

Although, at 1,400 MW, the Dinorwic scheme will become the largest in Europe, its purpose will be more for short term supplementation of supply than for bulk energy transfer for consumption over 12–14 h. In fact, the latter style of operation would require 20 installations like Dinorwic to yield even 10% of a demand of 100,000 MW (the probable installed capacity soon after 1990). This is an unreasonable objective for pumped storage in its present form, even though 10% of installed capacity is still well short of the ideal referred to earlier. Understandably, alternative forms of pumped storage are being earnestly explored.

Martin's concept and estuarine pumped storage

The necessary difference between the water levels in the two basins of a pumped storage scheme may be achieved by using surface and underground reservoirs, which suggests that the sea and natural caverns should be exploited where available. An alternative would be to follow the principles adopted by Martin, and store energy by increasing the difference between the levels in two basins formed in an estuary. This variation has been evaluated by my colleagues and I, resulting in the type of scheme shown in Fig. 3 (the preferred energy capacity and geological conditions would dictate the actual location of barrages).

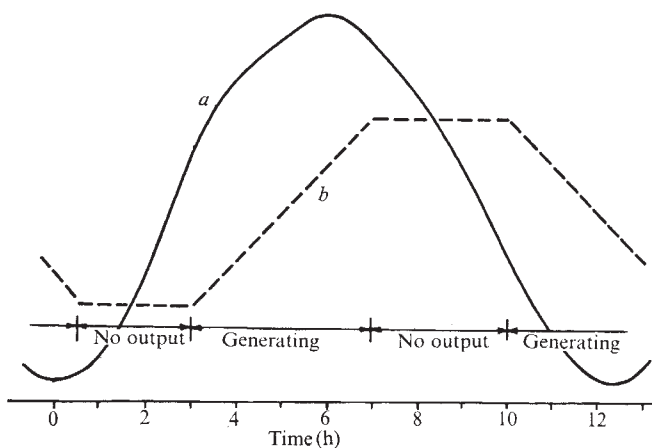


Fig. 2 Variations of tide level and the level in the basin, showing periods of generation.

The basic layout is somewhat different from that proposed by Martin (*et al.*), for here the second basin is small in area and sited entirely in deep water, so that the level can be reduced by pumping at night to well below low tide level, without the effects being felt on the coastline. The level in the larger basin is raised during the same night time period, but not to a level higher than that of the present high spring tide, thus avoiding problems of land drainage and removing the risk of floods which result from exceptional tidal surges.

From a scheme such as this it is possible to withdraw 4,000 MW at a constant rate (if that proves to be the preferred style of output) over the same 12-hour period every day, irrespective of the tidal range. The power from thermal

stations supplied to the scheme at night is also 4,000 MW, over a period of nearly 8 hours (the need for weekend variations in this pattern is recognised). This equality between the rates of pumping and generation makes the best use of available equipment. The scheme (Fig. 3) could be supplying 6% of daytime consumer demand by the mid 1980s, which, from one power station, is a reasonable increase in generating capacity. Similar but larger projects, operating in the Severn Estuary–Bristol Channel, could also be devised.

Economic and other factors

The economical value of a scheme of this type can be assessed on the following basis. For night time pumping using energy from thermal stations, the alternative to estuary storage on the scale of the scheme I have discussed (Fig. 3), would be three schemes each bigger than the Dinorwic project. In addition, harnessing tidal energy by the simplest of projects, akin to the 1933 scheme (Fig. 1) but involving the main enclosing dam shown in Fig. 3, would require a similar, additional amount of pumped storage potential. Making provision for this in an estuary, in such a way that firm daytime output is available, makes the scheme in Fig. 3 equivalent to thermal plant of the same capacity operated only by day. This equation should also take into account the fact that the tidal-pumped storage scheme permits other thermal plant to be run continuously rather than be cycled.

The combined estuary scheme would thus displace the equivalent generating capacity of nuclear plant having a cycling capability, that is an installation costing at least £1,400m—probably much more—at 1974 prices. This scheme would have a capacity of 4,000 MW and its operation could be achieved by the estuary project but without fuel costs other than for the purchase of energy at night from thermal stations. On this basis it is realistic to believe that the estuarine scheme is both economically preferable and operationally equivalent to the nuclear alternative.

Many other factors have to be considered in the moderately complex but technically straightforward operation of this type of estuary development. Basically, it is little more demanding on plant than are other tidal proposals, even though its performance is easily rendered compatible to energy requirements, through the pumped storage addition. Unlike the next round of nuclear stations the estuary scheme relies heavily upon proven technologies. Only two main components are involved, embankment construction, which has been explored in great detail, especially by the Dutch, and pump turbines. Several new types of hydraulic machine for extracting energy from small differential water levels have been devised recently, and these may be well suited to estuarine tidal schemes. Machines pioneered by the French in the 1950s, for the small tidal scheme at La Rance, Brittany, have now been well proven over many years of service, and would also meet this duty.

It is worth recording that the French project is similar in size and purpose to the Dounreay and Winfrith nuclear installations: all are about 250 MW and, although experimental, they are also useful contributors to the national network. To scale up their costs *pro-rata* would be as inappropriate as applying costs from La Rance to the proposed scheme (Fig. 3) in the Severn Estuary, or to the large Ile de Chauey project, for which La Rance was the pilot. In fact, Ile de Chauey was shelved as soon as La Rance was completed, because it was essentially a tidal energy project with the attendant disadvantages already outlined (it had been envisaged that there would be some pumping when the tides permitted).

Environmental considerations

The energy figures discussed here for the combined estuary installation, were evaluated within specified environ-

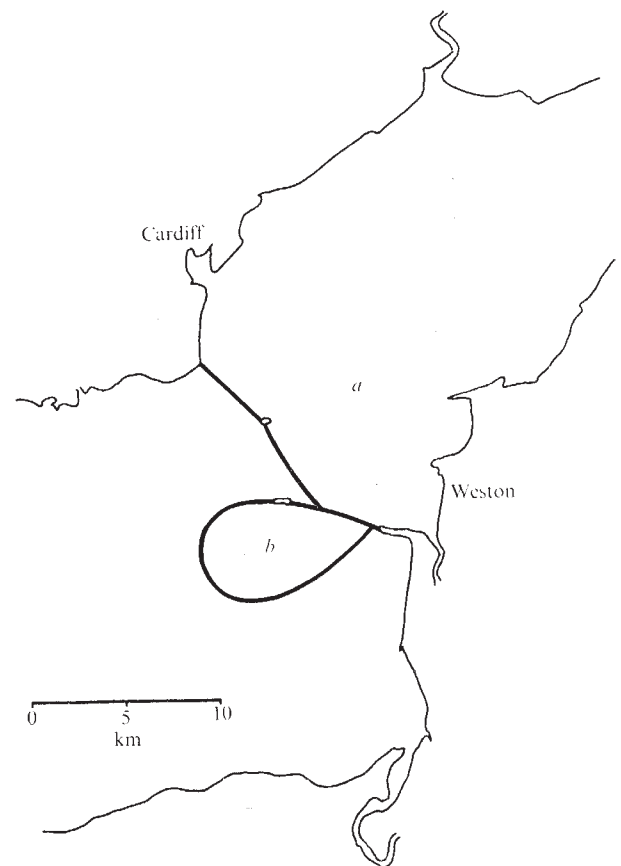


Fig. 3 Suggested barrage scheme: a, high level basin; b, low level basin.

mental restraints; more energy could be provided but this would create less acceptable conditions elsewhere. Land drainage and flooding have already been mentioned as factors limiting the height of the water level along the coastline. The high tidal range in this comparatively shallow estuary creates strong currents and exposes extensive mud flats at low water. Because of the currents, a large amount of sediment is held in suspension, and much of this settles out when the tide turns. Very little material seems to move seawards into the Bristol Channel, and therefore reservoirs constructed as shown in Fig. 3 should not suffer problems of sedimentation: the bulk of the material would be deposited over the area of the main reservoir in a layer consolidating to an average depth of only a few millimetres. Further inputs of sediment from the rivers could give rise to some local accumulations of deposits, but as there would be a 'tide' range of over 10 feet in this reservoir, currents of a strength comparable to those occurring in many estuaries and coastlines would still occur.

The loss of the mud flats over much of the estuary will not be generally mourned, although there would be some ecological effects. The present combination of strong currents and high concentrations of suspended solids leaves little room for sustained marine life, and reduced currents and improved water clarity would, therefore, generally improve feeding conditions. This should promote greater fish populations, and these would pass through the large, slowly rotating pump/turbines.

Wildfowl must also be considered in any review of environmental factors. One of the most extensive areas of mud flat used for feeding is Bridgwater Bay, immediately seaward of the barrages outlined in Fig. 3. The tidal regime for this area would remain largely unaffected although there would be some reduction in the currents. Further up the estuary the substantial rise in mean water level caused by

the barrage, would become less significant than the higher levels created at present by the tidal surge. The low water levels, which are influenced more by the general bed profile of the river system than by tidal processes, would change relatively little. Thus, at the Slimbridge Wildfowl Trust, upstream of Sharpness, the pattern of flooding and exposure of feeding grounds might be influenced more by the 24-hour cycle of operations than by the modified range of water levels created by a barrage.

Overall effects

The future for tidal energy may be bleak, but an integrated estuary pumped storage project of the sort described offers worthwhile economic and operational advantages over a pure tidal development. In particular, because circumstances at present and in the foreseeable future favour such a project, it is timely to give the matter closer attention. Industrial, social and environmental matters must not be overlooked, not least because these could and should be permitted to

benefit from such a project.

Some environmental aspects have been referred to above. On balance it seems that a net improvement over the present, somewhat suppressed ecological regime could be achieved, although more detailed studies of several aspects are required if there is to be an adequate picture of the probable changes resulting from a barrage. Many industrial and social factors also arise, such as benefits to shipping, inland road and rail communications, and the provision of a very large area for water recreation in a part of the UK that has managed to attract a population of three million despite the lack of social appeal of its estuarine focus.

It is to be hoped that energy planning in such circumstances would not be daunted unduly by the prolific interaction of seemingly complex factors, especially as even the potential power output need not be reduced significantly in order to provide other sectors of the community with wide benefits that are, in their own way, just as much in the rational interest.

Nuclear options

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Dr G. R. Bainbridge is Manager of Technical Assessments in the Reactor Group of the United Kingdom Atomic Energy Authority. At the beginning of August he takes up his appointment to the new Chair of Energy Studies in the University of Newcastle upon Tyne. Here, he discusses the nuclear fission reactor options which Britain could take up during the next decade and gives an outline of the broad energy requirements for which nuclear reactors are needed.

BRITAIN took a first option which led towards the application of nuclear fuel to supplement traditional coal and oil supplies almost 30 years ago. It was to pursue techniques for controlling nuclear fission reactions on a large scale, thus making heat available, and manufacturing plutonium. Most of the nuclear research and development work in the world at that time was financed by military budgets. The construction of the Calder Hall plant, the first unit of which was completed in 1956, was no exception. But its most remarkable success was in the supply of by-product electricity, design data and operational experience for the later commercial nuclear power stations. It is easily forgotten that Britain achieved her first peacetime nuclear power objectives quickly and alone. It would be sad if transient commercial expediency led the country to take risks now by adopting nuclear reactor designs from abroad which are in some respects technically less sound than those produced at home.

Britain now gets 10% of her electricity from nuclear power stations (Fig. 1) which use natural uranium fuel and thus save 9 million tons of coal, or 5 million tons of oil each year. That is, however, only 3% of the total national fuel requirement (Fig. 2) and there is recognised scope for a more significant contribution as time goes on.

When a country is embarked, as Britain is, on a course of applying such a rapidly advancing technology as nuclear power, it is of benefit to review periodically and unhurriedly the available alternatives. The most important review of the 1970s is now in progress, and it could have very important consequences for Britain's nuclear power strategy. With a wealth of nuclear experience to her credit, the country is

more favourably placed than ever before to survive any future shortages of fossil energy and rising fossil fuel prices, by arranging a strong nuclear power programme for electricity generation. Indeed, if a combined 'energy resources and use' strategy can be formulated to include a complementary plan for all of the available fuels, the 1980s should see Britain in a better position for energy than for many years past.

To reach that position, in which fossil fuels can be conserved or exported as well as being used rationally at home, I believe that action must be taken to provide most of our incremental electricity generating capacity, including replacement plants, in the form of nuclear power stations. This implies that 30,000–40,000 MW of nuclear capacity should be ordered in the next decade and built before 1990 (Fig. 3). A further 70,000 MW will have to be ordered

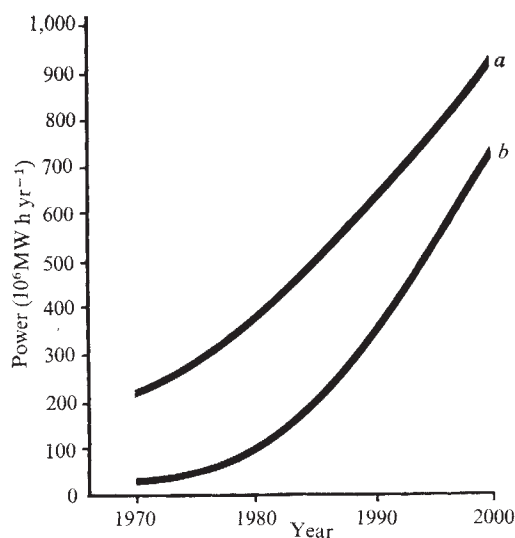


Fig. 1 The total electricity demand (a), and nuclear power supply (b), in the United Kingdom.

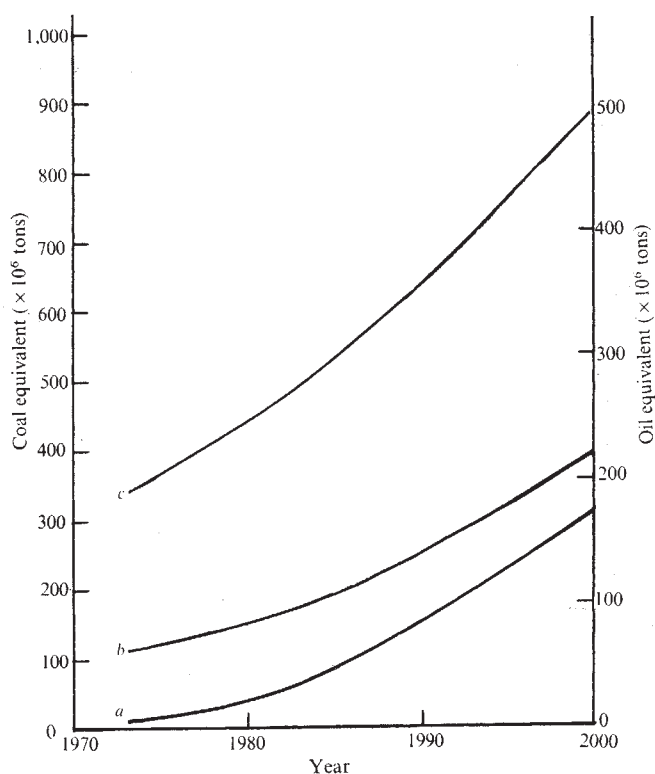


Fig. 2 Primary energy consumption in the United Kingdom. *a*, Nuclear electricity; *b*, total electricity; *c*, total.

between 1985 and 1995 for operation before the end of the century. That will enable nuclear power to supply in the region of 80% of the country's electrical energy usage (Fig. 2); around 30% of the country's total energy usage at the end of the century.

An expenditure of around £8,000 million will be required for the nuclear power station plant completed during the next 15 years alone, and £600 million will have to be spent on replacement fuel (Fig. 4). The task will not be easy to accomplish, even with a well established and financially strong National Nuclear Corporation (assuming that this is soon realised). The investment sum is over four times that of the first 20 years of commercial nuclear power. During

that period there have always been two or more consortia, or design and construction companies, working with the Electricity Boards in order to get the initial 10,000 MW or so of nuclear plant into operation. But British industry as a whole has achieved similar objectives previously. The expenditures on an alternative oil station programme for the same electrical capacity would be £4,000 million capital outlay, and almost £7,000 million for fuel; 30% higher than the cost of nuclear plant in those initial fifteen years of construction and operation. At no time after about the third year of operation would the total expenditure on an oil programme be less than that of a nuclear programme. From then on nuclear fuel would cost only £1,500 million a decade, whereas the 550 million tons of oil, which would be used during the same period, would cost £16,000 million. Similar figures emerge if coal, and not oil, is considered as an alternative to nuclear power.

If this main nuclear programme objective is to be achieved, then the other nuclear commercial options will have to be allocated a much lower priority. It can be anticipated, however, that although the types of nuclear reactor selected as the best that Britain could build next may be suitable for unit designs with a nett output exceeding 600 MW, with minimal adaptations some of them might be provided in smaller unit sizes overseas. At present, power stations with nuclear units of 300 ± 200 MW could be competitive with oil-fired designs, provided that the price of oil stays high in relation to that of nuclear fuel (at present about 6:1) and that the capital cost of oil plant relative to nuclear plant does not decrease (at present 0.7:1), (Fig. 5). For exports, which would relieve the pressures of commitment in a heavy home programme, a separate organisation of companies could be formed profitably, allied at home with the main National Nuclear Corporation, and overseas with interests already actively engaged in attracting nuclear power station business.

Other factors affecting the choice of reactor, such as the supply of industrial process and urban living 'comfort' heat, need to be considered separately from the main issues of this article. The provision of nuclear reactors for the propulsion of large, fast, container ships and oil tankers are also outside the main issues discussed here, as they would be additional and special in many respects.

If resources are to be used sensibly, and there is to be high morale and enthusiasm amongst those engaged in the

Table 1 Nuclear reactor options—parameters

	Magnox	Gas-cooled reactors			Water-cooled reactors				Sodium-cooled reactor
		AGR	HTR	GBR	SGHWR	BWR	PWR	CANDU	
Nominal reactor output available (MWe)	500–600	625	1,320	1,320	625	1,110	850	750	1250
Net efficiency (%)	32	41	38	35	32	31	32	32	42
Mean rating (MW h/t U)	3.1	12.6	112	250	19.8	25.9	38.2	22.1	202
Fuel	U metal	UO ₂	UO ₂	UO ₂	UO ₂	UO ₂	UO ₂	UO ₂	U/Pu O ₂
Mean fuel burn-up (MW d/t heavy atoms)	4,000	17,250	85,000	7% ha	22,050	28,000	32,000	9,600	6.9% ha
Fuel cladding	Magnesium alloy	SS	Pyro-carbon	SiC	Zircaloy	Zircaloy	Zircaloy	Zircaloy	SS
Coolant and temperatures:	CO ₂	CO ₂	He	CO ₂	H ₂ O	H ₂ O	H ₂ O	D ₂ O	Na
inlet (°C)	247	287	273	260	271	278	288	261	340
outlet (°C)	414	651	749	650	282	286	321	299	540
Coolant pressure (MPa)	2.9	4.1	4.2	6.6	6.7	7.4	15.2	11.0	—
(pound inch ⁻² gauge)	400	585	600	940	955	1,050	2,190	1,580	
Initial fuel weight (t heavy atoms/GWe)	1.011	195	23	{ 9.5 24.7 70.0	159	126	83	142	{ Core 14.4 Ax B 14.7 Rad B 32.5
Replacement fuel weight (t heavy atoms/GWe y)	286	52	11	{ 14.4 37.3 21.4	53	42	36	120	{ Core 11.4 Ax B 11.6 Rad B 8.6
Steam conditions at TSV:									
Temperature (°C)	400	538	538	538	277	286	266	254	490
Pressure (MPa)	5	16	16	16	6.2	6.6	5.5	4.2	16
(pound inch ⁻² gauge)	710	2,300	2,300	2,300	885	950	780	600	2,300

Table 2 Probable strategy

Year of order	1974	75	76	77	78	79	1980	81	82	83	
Year on-line	1981	82	83	84	85	86	87	88	89	1990	
Total nuclear capacity required ($\times 10^3$ MW)		2	3	3	2	4	5	5	4	6	7
AGR		1*	2*	1*	2†	3†	4†	2†	1†		
SGHWR		1		1							
HTR			1‡			1	1	2	2	6§	7§
Fast reactors				1‡				1	1		

* Likely to be delayed by late 1974 decisions, some giving way to water reactors or, even more likely, to coal and/or oil stations.

† Options based on further AGR/SGHWR experience.

‡ First commercial stations.

§ Options based on further HTR-FR experience and later, plutonium availability.

nuclear power station development and manufacturing industry, and if the paying public is to remain confident that nuclear power is in their own and the nation's best interests, then expeditious decisions must follow any review. This is particularly important when review procedures have been conducted at the highest political level, as has been the case in recent months. A Parliamentary Select Committee, an eminent Nuclear Power Advisory Board, four ministers and two governments have been involved.

Whether under the new policy, the established line of action is continued, or new, previously unforeseen conditions are met with a change of direction or pace, there must be adequate early publicity about the co-operation necessary for rapid progress. The present review must not end up as a little reported non-event, as did the thermal reactor and fast reactor reviews of a few years ago.

Nuclear reactor options

The objectives of low cost, plentiful, reliable, safely available nuclear energy must be kept in sight, for it is easy to be distracted and repeat old errors. Accepting these limited objectives, however, it is possible to argue that the logical progression in the use of gas-cooled reactor designs which Britain began to operate in the 1950s, could fulfil not only all her own needs but also those of some other countries. Table 1 gives typical parameters for gas-cooled reactors and for the main available alternatives.

Calder Hall was the first nuclear power station to feed substantial amounts of electricity into a national grid distribution system. The uprated output, now at 200 MW, regularly exceeds the original (perhaps conservative) intended output by 50%, and it also feeds process steam to the adjacent Windscale site. Moreover, its sustained per-

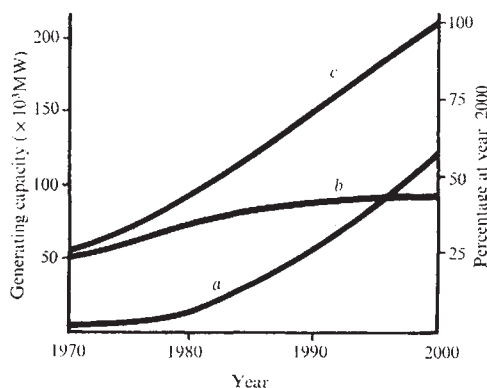


Fig. 3 Electricity generating capacity trends in the United Kingdom. *a*, Nuclear; *b*, fossil; *c*, total.

formance over almost 20 years (an accountant's plant amortisation period) is, together with that of its twin station at Chapelcross, better than that of any other plant in the world exceeding 100 MW in output, whether nuclear or fossil fired. Year after year it exceeds 90% load factor even though it has to be shut down occasionally for refuelling. Such is the confidence that these plant can continue to operate at a low cost, that there is a current survey of the components which could be refurbished usefully in order to give the stations 20 to 30 further years of life.

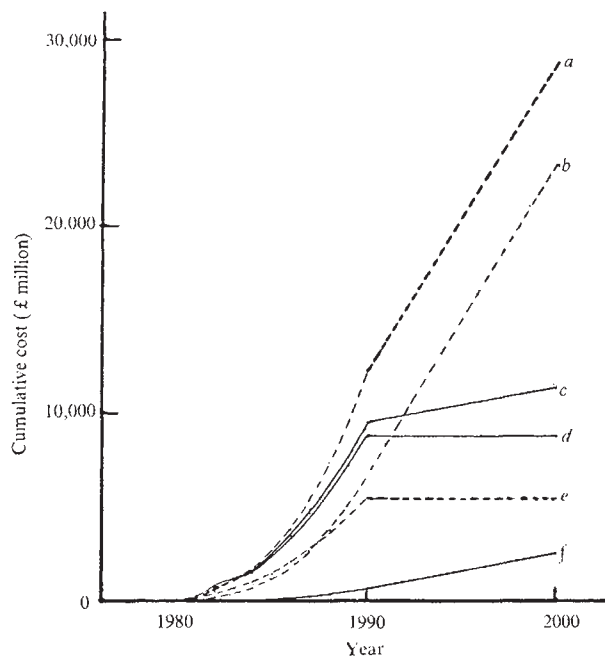


Fig. 4 Cumulative costs of alternative nuclear and fossil programmes completed between 1980 and 1990. *a*, Oil station plus oil; *b*, oil; *c*, nuclear station plus fuel; *d*, nuclear capital; *e*, oil capital; *f*, nuclear fuel replacement. This assumes that the cost of nuclear stations is £240 per kW (including the initial fuel charge); the cost of oil stations is £150 per kW; uranium costs about £6 per pound weight of U_3O_8 ; oil costs £30 per ton; there will be load factor of 70%; and a 10-yr programme supplying 37,000 MW of energy.

In 1955, when "A Programme of Nuclear Power" was announced in a White Paper, there was no doubt that the gas-cooled, graphite moderated, thermal neutron reactor, based on the Calder Hall, Magnox clad, natural uranium fuelled design, should be the first to be exploited commercially in Britain. During the 1960s, 18 reactors and associated plant in 9 stations were brought into operation (Fig. 6), providing an output of 5,000 MW. It was recognised then that other nuclear options would have to be taken before long, as it was expected that improved models would be built, and that a second type of reactor, liquid-cooled, might be used. So it turned out.

Following Hintonian guidelines to increase temperatures and efficiency and cut costs, the research and development design work was implemented during 1957–58 to enable the construction of an Advanced Gas-cooled Reactor at Windscale (WAGR). In order to limit expenditure its output was set at 35 MW of electricity, which it was believed would be sufficient to allow the core design to serve primarily as a test bed for higher rated, higher temperature uranium oxide fuel, slightly enriched in the more fissile ^{235}U isotope. It was also intended to provide data on the interaction between the graphite, the carbon dioxide coolant and the fuel, later determined as stainless steel clad, under onerous operating conditions. Since 1963, WAGR has been a prolific supplier of invaluable data for Britain's nuclear design teams. Yet it

has given a load factor averaging 84%, remarkable for a prototype plant.

The government, however, was prudently cautious in 1964 when considering the nuclear options for "The Second Nuclear Power Programme". As had been anticipated, other reactors had become available. These could use uranium more efficiently, and could reduce the capital cost of the power station and fuel to a lower level than had proved possible with the alternative Magnox (Mark 1) gas-cooled reactor designs. So tenders from British industry (in some cases including design features from foreign companies)

the debate extended from mid-afternoon until late evening, nuclear power is a non-party issue, and the day was Thursday (with a quiet Parliamentary Friday to follow) and so only about 50 'specialist' MPs attended and there was no sensational result. There was, however, strong support for the British reactor designs and it was agreed that whatever decision was finally reached, any reactor built in the near future must be safe.

No one in the nuclear industry, Parliament, the Nuclear Power Advisory Board or the government seems to doubt that the development of a high temperature gas-cooled reactor (HTR) will eventually be a sensible course of action. The timing of the construction of the first commercial station, in relation to the progress of development work in the Euratom Dragon project and to advances overseas (not least in the USA) has yet to be settled. It seems unlikely, however, that the first, large, Mark 3 gas-cooled reactor unit could be ordered soon, which means that such designs will not contribute to commercial nuclear power until the late 1980s. Bearing in mind the continuing need for the improvement of designs using ceramic particle fuel and higher temperature coolant circuits (which have helium instead of carbon dioxide) this is a project which would suffer if rushed. On the other hand, the longer term development potential of the HTR could usefully receive more effort. Ideas for using HTRs to generate electricity with gas turbines, and the application of HTRs to provide process heat, now seem to be moving ahead more quickly as collaboration with other countries is arranged.

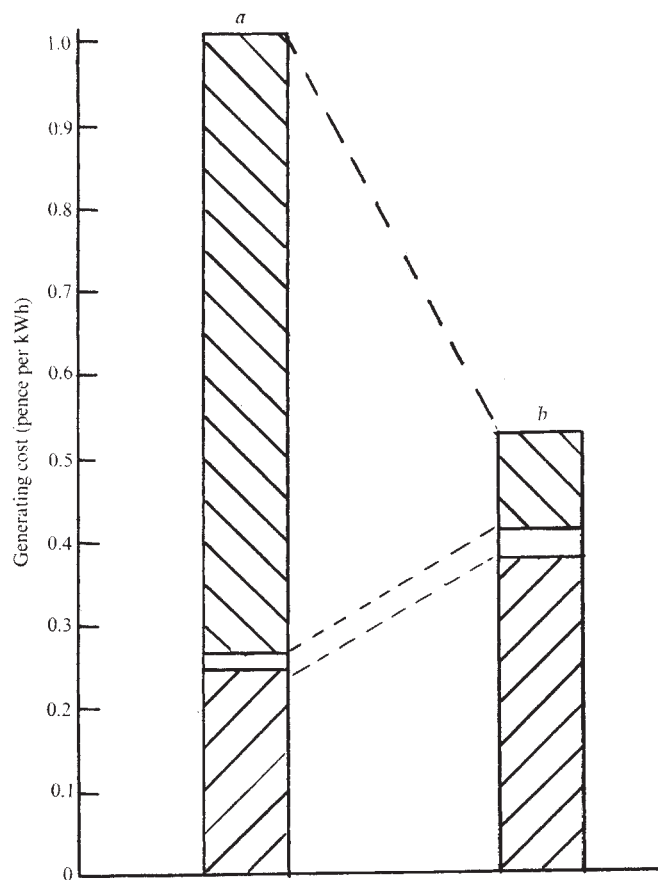


Fig. 5 Electricity generating costs in the United Kingdom. *a*, Oil; *b*, nuclear. In both columns the upper section represents the cost of fuel, and the lower section represents the capital outlay. The space separating the upper and lower sections represents the operational costs.

were considered, and an AGR (Mark 2) design was selected. The background of the assessment and the reasons for the choice were given in special Central Electricity Generating Board publications. A light water reactor design of boiling water type (BWR) was placed second, with pressurised water (PWR) and other AGR designs as runners up.

As a result of this, ten AGRs in five stations were ordered, to provide some 6,000 MW of output. The first two are now almost in operation. Though several PWR and BWR designs have been built more quickly overseas, many have suffered delays and extra costs. The AGRs use a steel cable prestressed concrete pressure vessel, an important safety development which was introduced into the last two Magnox stations. These have always been recognised as safe near urban locations. The LWRs of both kinds, however, have become the centre of a nuclear safety controversy in the United States.

The recent debate in the House of Commons, did not give a definite indication of the government's intentions in deciding between the wider range of nuclear options. Although

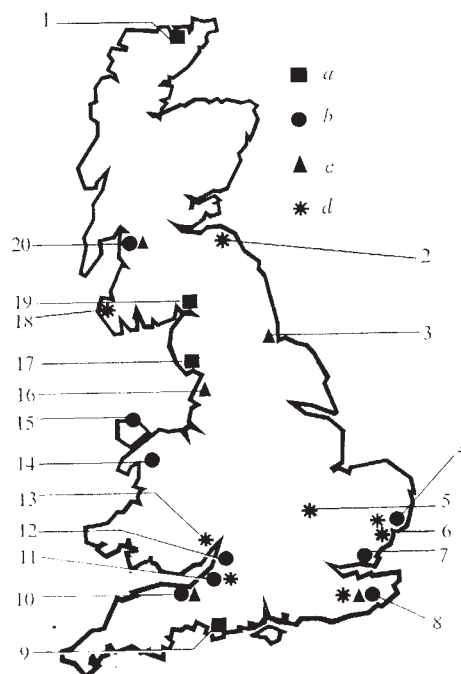


Fig. 6 Nuclear power in Britain. *a*, Experimental power stations; *b*, Magnox stations; *c*, AGR stations under construction; *d*, proposed stations. 1, Dounreay DFR and PFR; 2, Dunbar; 3, Hartlepool; 4, Sizewell 'A' and 'B'; 5, Molesworth; 6, Orfordness; 7, Bradwell; 8, Dungeness 'A', 'B' and 'C'; 9, Winfrith 'Dragon' and SGHWR; 10, Hinkley Point 'A' and 'B'; 11, Oldbury 'A' and 'B'; 12, Berkeley; 13, Portskewett; 14, Trawsfynydd; 15, Wylfa; 16, Heysham; 17, Calder Hall and Windscale Magnox and AGR; 18, Girvan; 19, Chapelcross Magnox; 20, Hunterston 'A' and 'B'.

The declared reluctance in some parts of the Central Electricity Generating Board to order more AGRs, can be expected to decrease as experience is gained with Hinkley Point B station and the South of Scotland Electricity Board's Hunterston B station. Both of these stations

are now almost in operation. Meanwhile, although forecasters have been perturbed by the low electricity demand of the past winter, it is felt that one or two stations of some other kind must be ordered soon to supplement firm power supplies in the early 1980s.

The case for building LWRs designed in the United States (particularly the PWR) in the meantime, has been strongly pressed by senior people in the CEBG and the National Nuclear Corporation (NNC)—a potential supplier under licence. Doubts that have arisen concern the safety of the thick steel pressure vessels and the pipework which comprise the coolant circuit, and the effectiveness of the emergency core cooling system (ECCS) in the event of a major fracture of the circuit. Much experimental work has yet to be done in the USA and other countries using LWRs, on both pressure vessel failure and ECCS during the next few years. There has been no publication of convincing evidence that, even if satisfactory safety solutions were known, any programme including the PWR would be better or cheaper than a programme using the British design. Factors bound to lengthen the programme and increase the costs are: import requirements, searching Electricity Board specifications, and the necessary quality assurance standards. It is important to avoid delays. For a large nuclear station, the interest charges on the committed capital, and the cost of alternative electricity supply into the grid system, can be of the order of 7% of the cost of the station for each month of delay. About 15 months of delay will double the cost. Project management and realistic construction programme planning are factors which are as important as plant design if improvement on past experience is to be obtained.

The case for building the British steam generating heavy water moderated reactor design (SGHWR) has been strongly pressed by the South of Scotland Electricity Generating Board and the Parliamentary Select Committee. The prototype 100 MW SGHWR power station which has been operating at Winfrith Heath in Britain since 1968, has resulted in an improved understanding of water reactors. The prototype incorporates many attractive features selected from the best of the earlier reactors. Not least of these is the modular pressure-tube construction of the core, avoiding the thick steel pressure vessel which characterises the LWRs. Experience in the operation of the Winfrith SGHWR has been good so that larger stations could now be built, with or without support from similar pressure tube reactor work in Canada, on the CANDU and boiling light water types. As in the case of the LWRs, however, many power station engineers consider that it is a retrograde step back to saturated steam conditions for the turbine-generators, particularly as the superheat steam machines now in use in all advanced British base-load power stations would be needed again later in the programme. It is possible, however, that because of the amount of nuclear power needed in Britain, there may be room for a few SGHWR designs. Interested countries abroad would then have some indication of the effectiveness of the design in larger scale operation than has been possible at Winfrith Heath.

In due course, fast neutron breeder reactors will be needed to ensure the better use of uranium resources. By converting ^{238}U (or ^{232}Th) into the more fissile ^{239}Pu (or ^{233}U) they can enable possibly a 50 fold reduction in uranium needs. They can also use waste ^{238}U from earlier isotope and uranium-plutonium separation plant operations, and ensure that natural uranium continues to be available at acceptable prices for the thermal reactors still operating.

Encouraging progress towards commercial sodium breeders is now becoming apparent, with the French Phenix and British PFR in operation. Only three factors could delay the establishment of commercial lead stations in

continental Europe and Britain in the early 1980s: first, the inability to demonstrate that a programme of such reactors could be built with capital costs low enough to allow electricity to be generated as cheaply as is possible using contemporary thermal reactors; second, poor explanation to the public of the exceptional value of plutonium as a 'perpetual motion' fuel; and finally, poor explanation to the public of ways that plutonium can be managed in the fuel cycle external to the reactors.

Gas-cooled breeder designs would have been much further advanced if at the time of initial consideration prestressed concrete vessels had been available to ensure safe designs, which steel vessels could not. Gas-cooled reactors would have been a logical next step beyond the AGR and HTR. While a European Gas Breeder Reactor Association is now pursuing limited objectives in the fuel design and plant layout areas, large scale expenditures are unlikely, and progress is likely to be slow as long as success with sodium-cooled breeder reactors remains a possibility.

Probable strategy

The basis of probable future strategy (Table 2) is that gas-cooled reactors of the Magnox (Mark 1) type have worked well and given invaluable experience for later developments. It can be expected that gas-cooled reactors of the AGR (Mark 2) type will soon begin to work well and that the difficult problems of the earlier designs can be avoided through more careful specification of plant yet to be ordered, particularly concerning the boilers and the insulation of pressure vessel liner. It is agreed that development work towards gas-cooled reactors of the HTR (Mark 3) type should be continued because of its potential for electricity and process heat applications. Thus, gas breeder reactors (Mark 4) could be achieved, which in a large-scale, fusionless, national energy system of the distant future, might have a place complementary to, or even supplanting, the most advanced sodium breeder reactors. They would not operate, however, before 1995.

A further basis of this strategy is that if water-cooled reactors are required, it will only be to a very limited extent, and there is not a justifiable case for importing their technology into the PWR or BWR designs at considerable cost. Proving their safety would give continuing difficulty in Britain. Sufficient progress has been made with the British SGHWR to exploit its capability now commercially in a few larger stations, while the AGR matures to full credence. An alliance of British SGHWR and Canadian knowledge with similar plant should mean that some overseas customers will become confident enough to order water-cooled power stations from the combined organisation. This might not occur if Britain and Canada continue to operate separately.

It does not ease the problems of a country to have too many parallel lines of development simultaneously. In particular, it is not beneficial to build contemporaneously too many prototype or lead power stations. With the choice of gas-cooling as the main line, and sodium-cooling as an option for the future, Britain would seem to have sufficient scope but not excessive problems. If there are benefits from water-cooled designs, as there seem to be in the small sized unit overseas market, these will come with slight extension of present commitments through SGHWRs. That obviates the greater effort required to understand and necessarily improve the LWR technology by importing PWR designs. Britain could and should buy technological expertise from abroad when it is lacking at home, but in the nuclear power field this is unnecessary at the present time. Indeed, she has available to other countries valuable gas-cooled, water-cooled and sodium-cooled reactor technology, which improved marketing could turn to benefit.

DNA fragments carrying genes for tRNA^{Tyr}_I

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The duplicated genes coding for tRNA^{Tyr}_I have been isolated using site-specific nucleases and gel electrophoresis. An unduplicated sequence of 4–120 base pairs separates the two genes. Specific DNA fragments can be obtained in sizes appropriate for both functional and structural analysis of the tRNA^{Tyr}_I region.

ONE approach to studying the detailed structure of a transfer RNA gene involves the chemical synthesis of the relevant deoxyribonucleotide sequences¹. A major barrier to alternative approaches has been the problem of isolating genomic sequences of the appropriate size and purity. Several preparations of DNA enriched to various degrees for regions complementary to transfer RNA have been described^{2–5}. In the experiments reported here, the genes for tRNA^{Tyr}_I have been obtained as small DNA fragments using a combination of several site-specific endodeoxyribonucleases and polyacrylamide-agarose gel electrophoresis^{6,7}.

In *Escherichia coli*, three genes for tRNA^{Tyr} have been identified. The gene coding for the major species, tRNA^{Tyr}_{III}, (70% of the total tyrosine accepting activity), maps at approximately 78 min (refs 8–10). The two genes which code for the minor species, tRNA^{Tyr}_I, occur as a duplication near the attachment site for bacteriophage Φ 80 (refs 11–13). (The term gene is used here to indicate that sequence of bases coding for each tRNA. There is no evidence at present to indicate whether the two tRNA^{Tyr}_I genes are transcribed as a single RNA molecule, as is found for tRNAs coded by bacteriophage T4 (ref. 14).) The tRNA^{Tyr}_I genes are only distinguishable from one another in *su*⁺ cells where one of them has a single base change in the anticodon region^{15,16}. This suppressor phenotype has made possible the isolation of several different transducing derivatives of bacteriophage Φ 80 as well as the isolation and biochemical characterisation of mutants deficient in various aspects of tRNA function^{17–19}.

Three phages have been used as sources of DNA. The phage Φ 80h *psu*⁺ (double copy phage or 'doublet') is a nondefective transducing phage carrying both genes for tRNA^{Tyr}_I. The phage Φ 80h *psu*[–] (single copy phage or 'singlet') is a phage derived from the doublet phage by an unequal recombination event between homologous sequences, such that one of the two tRNA^{Tyr}_I genes has been eliminated (see Fig. 6, inset). The phage from which the transducing phage were derived is Φ 80h amb1 and will simply be referred to as Φ 80h or parental¹¹.

DNA digestion profiles

The site-specific nuclease endo R·Hind, (prepared from *Hemophilus influenzae* Rd according to the procedure of Smith and Wilcox²⁰), was used to digest DNA isolated from Φ 80h, the doublet transducing phage and the singlet transducing phage. When the limit digestion products are compared by gel electrophoresis, the three profiles are found to be congruent for a majority of the fragments (Fig. 1). Our conclusions here are based upon composite data obtained from the application of several different electrophoretic conditions, each chosen for its ability to resolve optimally a particular group of fragments. To facilitate comparison of the three DNA digests, a schematic diagram combining the data from several electrophoresis condi-

tions is given in Fig. 2. Construction of this composite is accomplished by including an overlap of well resolved fragments in each experiment. The band differences between the three DNAs provide convenient landmarks for confirming the alignment of profiles.

There are three fragments which are unique to Φ 80h DNA (A4, A6 and E4). There are five fragments which are absent from the Φ 80h digest but which occur in both the singlet and doublet digests (A4a, A6a, D1a, F3a, F3b). These are called transducing-unique. In addition, there is one singlet-unique fragment (C1a) and one doublet-unique fragment (B10a).

Hybridisation

The ability to hybridise with ³H-tRNA^{Tyr} (ref. 21) has been tested for each of the seven fragments unique to the DNA of the transducing phages. These unique bands, and several others which are common to all three phages, were eluted separately from preparative-scale gels. The only fragments showing any significant hybridisation with ³H-tRNA are the

Table 1 Hybridisation of isolated fragments with ³H-tRNA^{Tyr}

DNA type	DNA fragment	³ H (c.p.m./filter)	³ H (c.p.m./pmole DNA fragment/filter)
Singlet	B 8,9	2.1	8.6
Singlet	B 11	1.9	3.6
Singlet	C 1a	28.4	56.6
Singlet	C 3	1.8	7.0
Singlet	C 4	0	0
Singlet	D 1a	0.8	3.1
Singlet	D 2,3,4	0.7	5.7
Singlet	E 1	0	0
Singlet	E 5	0	0
Singlet	F 3,3a,3b	0.1	0.4
Doublet	A 1,2,3	4.3	83.3
Doublet	A 4,5	4.0	10.0
Doublet	A 6,7	12.3	76.7
Doublet	A 8	3.0	16.7
Doublet	B 1	7.0	40.0
Doublet	B 2,3,4	9.7	56.7
Doublet	B 5	11.0	56.7
Doublet	B 6	9.3	50.0
Doublet	B 7	10.3	63.3
Doublet	B 8,9	58.0	395.0
Doublet	B 10a	194.7	1047.0
Doublet	B 10	60.0	330.0
Doublet	B 11	4.0	23.3
Doublet	C 1	1.3	10.0
Doublet	C 2	3.7	20.0
Doublet	C 3,4	4.0	23.3

DNA fragments were prepared from ³²P-labelled singlet and doublet DNAs (2 × 10³ c.p.m. μg^{–1} at the time of hybridisation) by preparative gel electrophoresis and electroelution from excised gel strips. After phenol extraction and dialysis, DNA was denatured in 0.2 N NaOH at 20° C for 15 min, neutralised with Tris-HCl, and brought to 6×SSC. Fifteen microlitres, containing 27 pmol of fragment were spotted immediately onto a dry 13 mm Millipore filter, which had been prewashed successively in 6×SSC and distilled water. DNA filters were exposed, while still wet, to ultraviolet light at 22 cm from a 15 W GE germicidal lamp (5 min per side), then dried for 3 h at 80° C under vacuum. To remove loosely bound DNA before hybridisation, filters were washed in 6×SSC, 0.1% Sarkosyl for 30 min at 20° C, then for 30 min at 67° C. Hybridisation was carried out in 6×SSC, 0.1% Sarkosyl, with ³H-tRNA (2 μg ml^{–1}) at 67° C for 8 h. The ³H-tRNA preparation was enriched for tRNA^{Tyr} on B-D Cellulose²². Following hybridisation, filters were washed, treated with T₁ and pancreatic RNase as described²¹, and counted in omnifluor.

singlet-unique fragment, C1a, and the doublet-unique fragment, B10a (Table 1). There is occasionally a small amount of hybridisation observed in the bands immediately adjacent to C1a and B10a which is an artefact encountered in slicing the preparative gels and eluting bands. For example in Table 1 band B8,9 shows some evidence of hybridisation in doublet DNA where it is adjacent to B10a; however, in singlet DNA which contains C1a instead of B10a, the B8,9 band does not show any hybridisation.

The strongest statement permitted by the limitations inherent in the hybridisation experiment is that a particular fragment does carry a significant portion of the tRNA^{Tyr} gene. It cannot

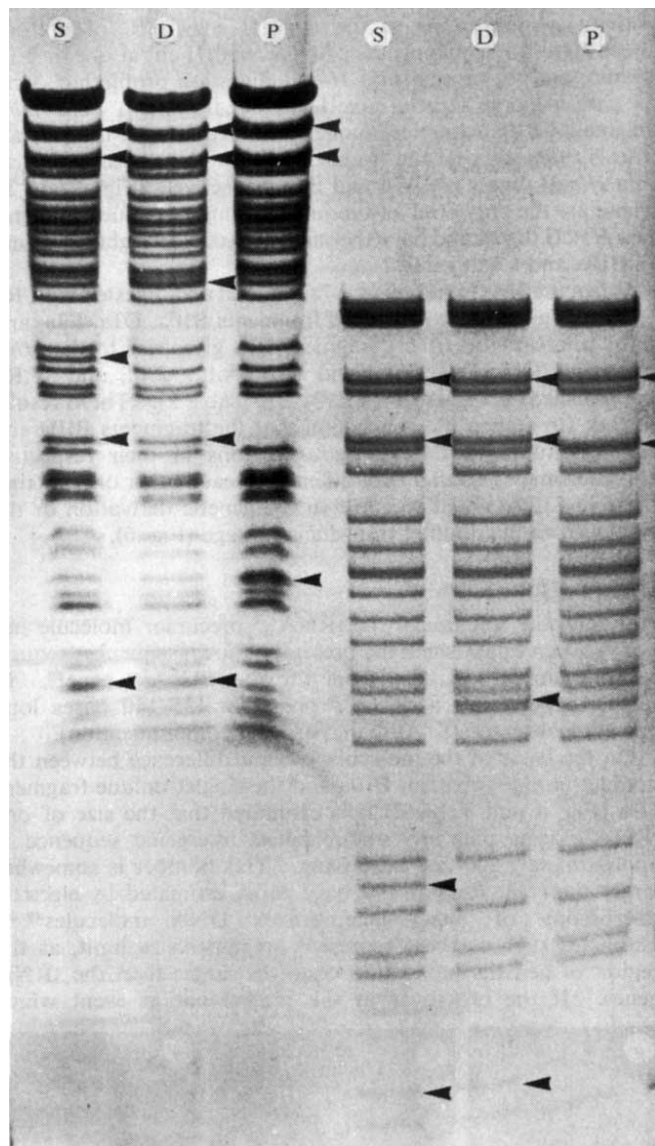


Fig. 1 Digestion profiles of $\Phi 80h$, doublet and singlet DNA produced by endo R·Hind. Growth of phage and preparation of DNA were as described previously²³. All endonuclease digestions were carried out for 4.5 h at 37°C in 10 mM Tris-Cl (pH 7.9), 6.6 mM MgCl₂, 6.6 mM mercaptoethanol, 60 mM NaCl with DNA at 200 μ g ml⁻¹ and using amounts of endonuclease sufficient to yield limit profiles. Unless specified otherwise all gels were made and run in Tris-Borate buffer (pH 8.3), have the composition 2% acrylamide (0.1% N, N'-methylene-bis-acrylamide), 0.5% agarose and were stained with Stains-all⁷. Electrophoresis was carried out at 200 V (11 V cm⁻¹) in EC apparatus flat plate cells cooled to 4°C. Digestions of $\Phi 80h$ (P), doublet (D), and singlet (S) DNA were divided into two aliquots; lanes 1-3 each contain 40 μ g of DNA and were electrophoresed for 3 h; lanes 4-6 each contain 10 μ g of DNA and were electrophoresed for 6 h. Unique fragments (those not common to all three) are indicated by arrowheads (see text). For identification of the unique fragments see Fig. 2.

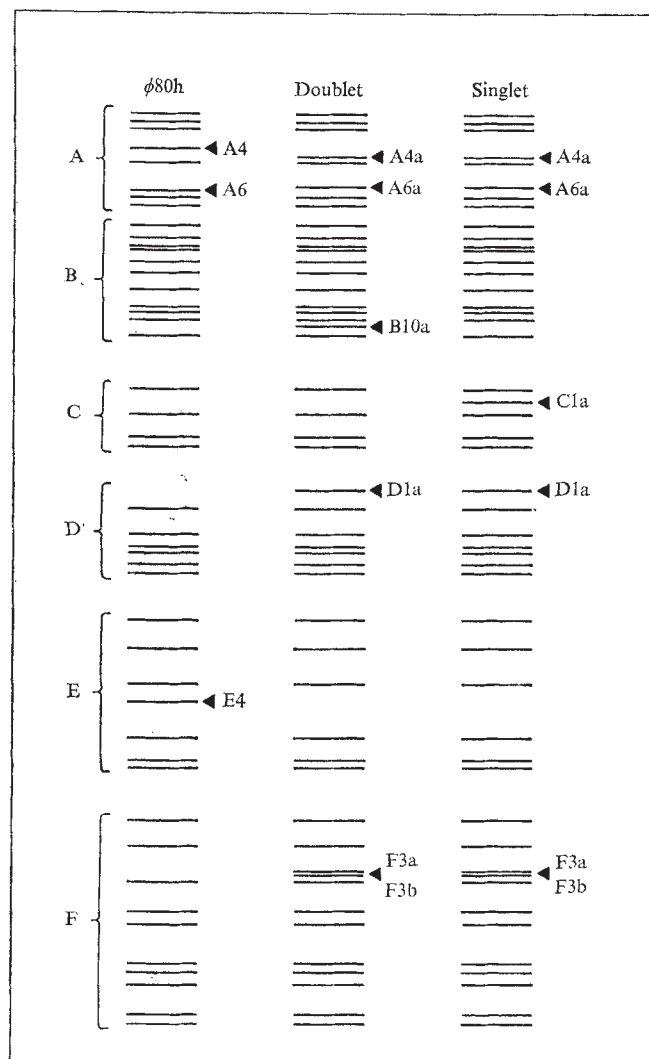


Fig. 2 Schematic diagram of Hind digestion profiles of $\Phi 80h$, doublet and singlet DNAs. The relative migration distances are based on a 2% acrylamide-0.5% agarose 45 cm gel profile. Arrowheads indicate those bands unique to one or two DNAs (compare with Fig. 1). Band nomenclature is based upon the $\Phi 80h$ profile. Bands falling into visually separated groups are assigned letters A-F, and fragments within a group are assigned consecutive numbers in order of migration distance. Labels for the fragments unique to singlet and/or doublet DNA are derived from the nearest non-unique fragment by the addition of a small letter (see ref. 23).

be ruled out, on the basis of these experiments alone, that some other fragment(s) may also carry a portion of the tRNA^{Tyr} gene which is either too small to be detected in the assay or which codes for those precursor sequences not found in the mature tRNA (ref. 22).

Integrity of tRNA^{Tyr} genes

The question of whether all the sequences coding for the mature tRNA^{Tyr} reside on the singlet-unique (C1a) and doublet-unique (B10a) fragments can be restated. Is there a nuclease recognition site within the tRNA gene(s) (including, in the case of the doublet DNA, any unduplicated intergenic region)? The following analysis is based upon two assumptions. First, the generation of the single copy transducing phage from the double copy transducing phage was by a mechanism not more complex than that deduced from the genetic data (ref. 11 and Fig. 6 inset). Second, if a nuclease-sensitive site exists in one region specifying tRNA^{Tyr} it also exists in the other¹⁶.

The distribution of fragments unique to each of the phage DNA digestions sheds some light on this question. The

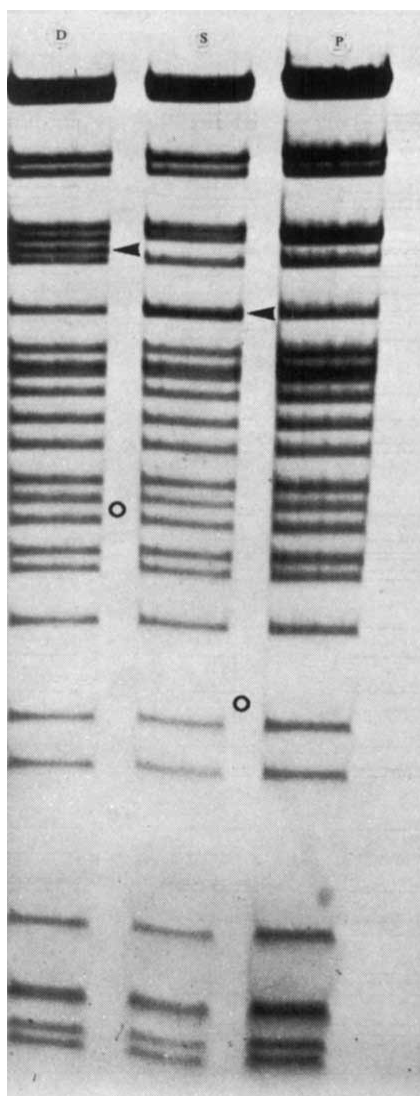


Fig. 3 Digestion profiles of $\Phi 80h$, doublet and singlet DNA produced by endo R-*Hinc*. Endo R-*Hinc*, purified from *Hemophilus influenzae* Rc (23) was used to obtain limit digestions of $\Phi 80h$ (P), doublet (D) and singlet (S) DNA. Conditions of digestion and electrophoresis were as described in Fig. 1 except that electrophoresis was for 5 h. The *HincII* and *Hind* (*HindII* and *HindIII*) digestion profiles of $\Phi 80h$ DNA are identical except for four fragments unique to *HincII* and eight fragments unique to *Hind* (ref. 23). Fragments unique to the *HincII* digestion are named for the nearest *Hind* fragment followed by a small letter suffix. Arrowheads indicate the *HincII* doublet-unique (A7a) and singlet-unique (B1a) fragments which carry the $tRNA^{Tyr}$ gene(s). (In these gel electrophoresis conditions, B1a is not resolved from B1.) $\circ$, Positions of the *Hind* $tRNA^{Tyr}$ containing fragments, B10a and C1a—missing in a *HincII* digestion profile.

existence of three $\Phi 80h$ unique fragments is a consequence of two nuclease recognition sites which exist in $\Phi 80h$ DNA but which are missing from the DNA of both transducing phages. In the transducing phages the segment of *E. coli* DNA has brought into the phage genome five nuclease-sensitive sites generating the six unique fragments in each phage. The conclusion that none of these five nuclease-sensitive sites is within the $tRNA^{Tyr}$ gene(s) derives from the fact that the singlet and doublet DNA digestions have the same number of fragments. If there were a nuclease-sensitive site anywhere within or between the duplicated sequences, then the number of unique bands in the doublet DNA would be one greater than the number in the singlet DNA and the ability to hybridise 3H - $tRNA^{Tyr}$ would have to reside in a band common to both phages.

Endo R-*Hind* (the phosphocellulose fraction of *H. influenzae* Rd) contains two ATP-independent nuclease activities each specific for a different deoxyribonucleotide sequence (ref. 23 and H. Smith, personal communication). The nucleotide recognition sequence of the two enzymes, *HindII* and *HindIII*, have been determined using T7 DNA (ref. 24) and λ DNA (K. Murray, personal communication) respectively. The fact that neither of the nucleotide sequences recognised by these two enzymes is contained in the sequence of $tRNA^{Tyr}$ (ref. 16) or in the known tRNA precursor sequence²² is consistent with the conclusion that no *Hind* nuclease cuts are made within the duplicated $tRNA^{Tyr}$ gene sequences.

Hemophilus influenzae strain Rc contains a nuclease, *HincII*, with a specificity identical to that of *HindII*, but lacks any activity corresponding to the *HindIII* enzyme²³. Therefore, those *Hind* fragments produced by a *HindIII* cut at one or both termini are not present in a *HincII* digestion profile but occur as part of some larger, *HincII*-unique, fragment. The *Hind* fragments B10a (doublet-unique) and C1a (singlet-unique) are in this category, and the fragments containing these sequences in a *HincII* digest are A7a and B1a respectively (Figs 1 and 3). These are the only doublet-unique and singlet-unique fragments in a *HincII* digest and have the same molecular weight difference as B10a and C1a (Table 2).

When the *HincII* fragment A7a is eluted and digested with Rd enzyme it gives rise to the *Hind* fragments B10a, D1a, F3a, and F3b; whereas, the *HincII* fragment B1a gives rise to the *Hind* fragments C1a, D1a, F3a, and F3b (A.L., C.F., and W.R., unpublished) (compare Figs 2, 3, and Table 2). These results further strengthen the conclusion that the fragments B10a and C1a originate from homologous regions in their respective chromosomes, and that they differ from each other only by that piece of DNA which was lost in the genetic derivation of the singlet from the doublet transducing phage (Fig. 6).

tRNA gene size

Although the full size of the $tRNA^{Tyr}$ precursor molecule has not yet been established, the presently known sequences require a minimum of 128 base pairs for the $tRNA^{Tyr}$ gene²². In further experiments a $tRNA^{Tyr}$ precursor 135–140 bases long has been observed (S. Altman, personal communication).

On the basis of the molecular weight difference between the doublet-unique fragment B10a and the singlet-unique fragment C1a (Fig. 4 and Table 2) it is estimated that the size of one $tRNA^{Tyr}$ gene plus any unduplicated intergenic sequence is approximately 200–260 base pairs. This number is somewhat larger than the size, 90–150 base pairs, estimated by electron microscopy of intact heteroduplex DNA molecules^{25,26}. Estimates such as these represent an upper size limit, as the region of genetic duplication could be larger than the tRNA genes. If the crossover in the recombination event which

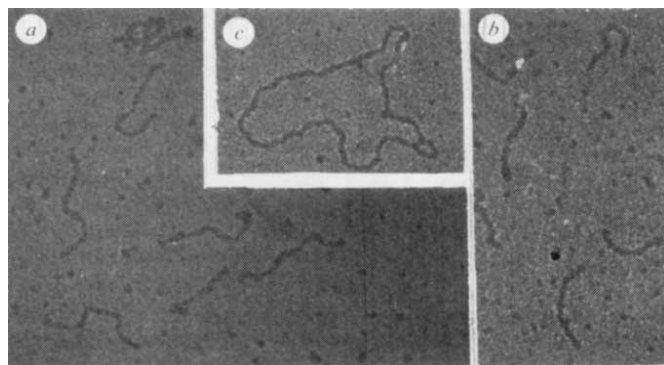


Fig. 4 Electron micrographs of (a) doublet-unique (B10a) and (b), singlet-unique (C1a) fragments. DNA fragments were prepared as described in Table 1. $\Phi X174$ RFII circles, (c) (molecular weight 3.4×10^6 daltons) were included as internal standards for the contour length determination of fragment size. The electron micrographs were made by Nancy Brimlow in the laboratory of David Freifelder²⁸.

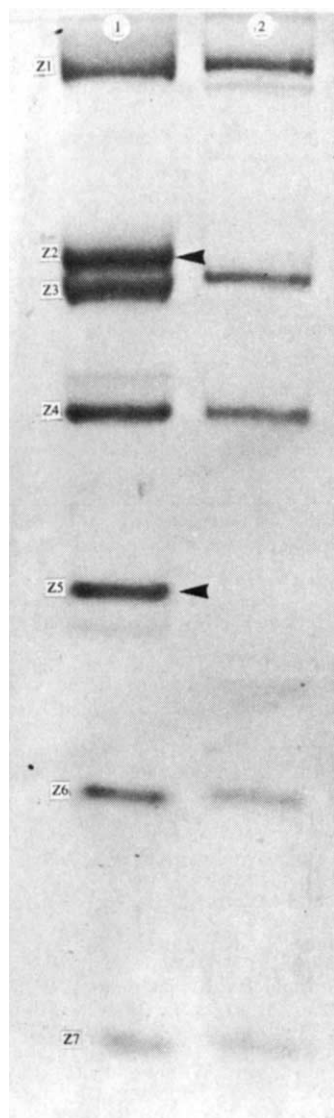


Fig. 5 Digestion of the doublet-unique (B10a) and singlet-unique (C1a) fragments with endo R·Hae. Endo R·Hae was prepared from *Hemophilus aegyptius* as described by Middleton *et al.*²⁷. Pure singlet-unique fragment C1a was prepared as described in Table 1. B10a was obtained free from contamination by neighbouring fragments by isolating the *HincII* doublet-unique fragment A7a, digesting it with endo R·Hind, and electrophoresing the digest to obtain the pure B10a product. Fragment B10a (lane 1) and fragment C1a (lane 2) were digested with endo R·Hae using the same digestion conditions as described in Fig. 1, and electrophoresed in a 5%–0.5% acrylamide-agarose gel for 3 h at 300 V. Fragments derived from B10a are numbered consecutively Z1–Z7. Fragments derived from C1a are assigned the number of the homologous fragment derived from B10a. Arrows indicate those fragments derived only from B10a: Z2 and Z5.

generated singlet from doublet took place outside the limits of the tRNA genes, then the doublet phage and singlet phage would differ by a correspondingly greater number of base pairs. This question will be answered in the course of the nucleotide sequence analysis of this region.

Taking the size of the tRNA gene plus spacer to be approximately 150×10^3 daltons (Table 2), the doublet-unique B10a and singlet-unique C1a fragments are two to three times the absolute minimum size necessary to contain the genomic regions coding for tRNA^{Tyr}.

To obtain a subset of smaller tRNA^{Tyr} gene fragments, purified doublet-unique fragment (B10a) and singlet-unique

fragment (C1a) were digested with endo R·Hae (from *H. aegyptius*) (ref. 27). The resulting fragments are well resolved on 5% gels (Fig. 5). Five of the seven fragments derived from the doublet genome have mobilities identical to those of the five fragments from the singlet genome. At the observed level of resolution this degree of coincidence can be taken as strong evidence (that is, as a fingerprint) that the two parental molecules, B10a and C1a, possess large regions of identical sequence.

Table 2 shows that, within experimental error, the molecular

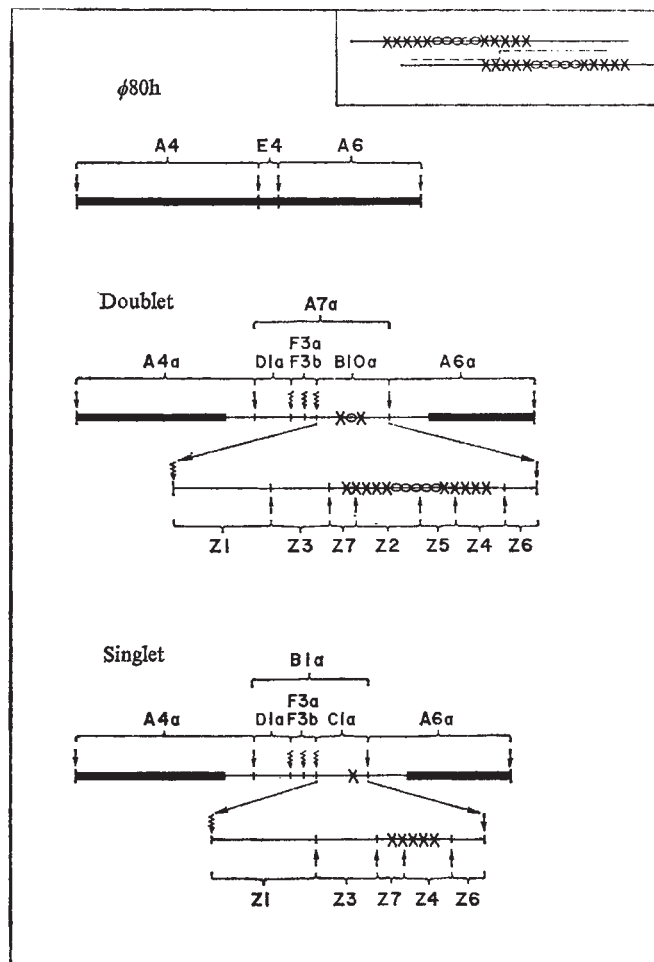


Fig. 6 A model, relating the fragments produced by *HindIII*, *HincII* and *Hae* nucleases. Homologous segments of the three phage genomes $\Phi 80h$, doublet and singlet are shown: phage DNA (—), *E. coli* DNA (—), *E. coli* DNA duplicated in doublet phage and containing tRNA^{Tyr} sequences (—X—), *E. coli* DNA found only in doublet phage, that is, nonduplicated intergenic sequences (—0—). The cleavage sites of the three different enzymes are marked: *HincII* or *HindII* ($\downarrow$), *HindIII* ($\uparrow$), *Hae* ($\uparrow$). The DNA fragments are labelled and drawn to the same relative scale, or expanded 5 times, as indicated (for assigned molecular weight values see Table 2). Of the four fragments derived from the *HincII* fragments A7a (doublet) or B1a (singlet), F3a and F3b are the only two which appear in a digest of intact singlet or doublet DNA with *HindIII* enzyme and must therefore be internal. As Z2 and Z5 are the only *Hae* fragments unique to doublet DNA, they must be adjacent and include all of the unduplicated intergenic sequence (—0—). (If there were no *Hae* sites in the unduplicated intergenic region only one doublet-unique fragment would be generated; two *Hae* sites in this region would give rise to three doublet-unique fragments, and so on.) The relative order of the other fragments is not determined nor is the location of the juncture between *E. coli* DNA and phage DNA. The size of each of the regions marked by (—X—) (the duplicated sequence) is between 135 and 230 base pairs and the size of the unduplicated sequence between them (—0—) is between 4 and 125 base pairs (see text). Inset: a representation of the out-of-register mispairing between identical doublet chromosomes, and an unequal recombination event (— —) which gives rise to the singlet chromosome (ref. 11).

Table 2 Molecular weights of 'unique' fragments from tRNA^{Tyr} region

HincII fragments	Phage derived from	Molecular weight (daltons $\times 10^{-6}$)	Hind fragments	Phage derived from	Molecular weight (daltons $\times 10^{-6}$)	Hae Fragments derived from B10a† and C1a*	Molecular weight (daltons $\times 10^{-6}$)
A7a	doublet	10.5	A4	Φ80h	14.0	Z1†*	1.75
			A6	Φ80h	11.0	Z2†	1.12
			E4	Φ80h	1.50	Z3†*	1.05
			B10a†	Doublet	5.6†	Z4†*	0.77
			D1a	Doublet	2.9	Z5†	0.54
			F3a	Doublet	0.93	Z6†*	0.33
			F3b	Doublet	0.93	Z7†*	0.22
			A4a	Doublet	13.7		
B1a	singlet	8.3	A6a	Doublet	11.3		
			C1a*	Singlet	4.1*	Sum B10a† fragments	5.78†
			D1a	Singlet	2.9		
			F3a	Singlet	0.93		
			F3b	Singlet	0.93		
			A4a	Singlet	13.7	Sum C1a* fragments	4.12*
			A6a	Singlet	11.3		

Fragment molecular weights were determined by electron microscopy and/or comparison of relative electrophoretic mobility with SV40 *Hind* DNA fragments of known molecular weight as described elsewhere²³. The horizontal arrows indicate which *Hind* fragments were derived from the *HincII* fragments A7a and B1a.

*, †, Derivation of individual *Hae* fragments from the parental *Hind* fragments B10a and C1a.

weights of the *Hae* fragments add up to the molecular weights of the fragments from which they were derived. The most interesting feature of the *Hae* digestion profiles is the existence of two doublet-unique fragments, Z2 and Z5. Their presence is evidence that there is some number of base pairs—a minimum of four for the restriction site (K. Murray, personal communication), which occur as an unduplicated sequence between the two sequences containing the tRNA^{Tyr} genes (Fig. 6).

tRNA^{Tyr} gene fragments

These results indicate the potential usefulness and feasibility of successive digestion-fractionation cycles using different nucleases with appropriate site-specificities. The DNA fragments in Fig. 5 are the final product of three such cycles using the nucleases *HincII*, *HindIII*, and *Hae*.

A model showing how the relevant fragments produced in each of the three digestions might be related to one another in the intact genome is shown in Fig. 6. As shown above, the maximum size for one tRNA^{Tyr} gene (including the intergenic sequence) is 200–260 base pairs. Taking the minimum size of four base pairs for the unduplicated intergenic sequence gives a maximum size of 256 base pairs for the tRNA^{Tyr} gene. Taking the minimum size for the tRNA^{Tyr} gene (135–140 base pairs) gives a maximum size of 125 base pairs for the intergenic sequence between the duplicated genes.

Each of the three endonucleases used in this work produces a different size tRNA^{Tyr} gene fragment. The *Hind* fragments B10a and C1a, which are two to three times the estimated size of the tRNA^{Tyr} gene(s) (plus intergenic sequence), are the most favourable size for studying *in vitro* the regulation and maturation aspects of tRNA synthesis and also the overall structure of the tRNA^{Tyr} genes. In both of these areas, the larger *HincII* fragments A7a and B1a may also prove useful. The seven *Hae* fragments, which are in the subgenic size range, are the most favourable for nucleotide sequence analysis.

The ability to isolate pure preparations of these fragments in chemical quantities should make a complete analysis of the tRNA^{Tyr} gene(s) a feasible prospect. Similar experiments are being carried out with the gene coding for tRNA^{Tyr}, the major species, on the premise that this comparison may help to identify those features of gene structure which are important in the regulation of tRNA synthesis.

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LETTERS TO NATURE

PHYSICAL SCIENCES

Radio spectra of OH471 and OQ172

RADIO spectra for the highly redshifted $z \geq 3.40$ quasars OH471 (ref. 1) and OQ172 (ref. 2) are presented here for frequencies between 16.7 MHz and 85.3 GHz. The spectra are complex. Both have a peak at or near 1.4 GHz and a second peak near or above 85 GHz. Both have a low frequency cutoff, the one for OH471 being especially sharp. OH471 sometimes seems to be variable at 31 GHz on a time scale of days but the source appears to be stable at 10.7 and 22 GHz.

Although flux densities for these sources had already been published at a few frequencies, the unusual nature of the objects encouraged us to undertake further measurements at as many frequencies and epochs as possible in order to obtain much more complete data in both frequency and time domains.

All observations, new and previously published, are listed in Table 1. The spectra of the sources are shown in Fig. 1. Figure 2 is a plot of flux density against time for OH471, which has shown some evidence of variability. The observations involve more than 120 measurements at many epochs from 1963 to March 1974 at 25 different frequencies between 16.7 MHz and 85 GHz.

Flux densities have been adjusted to the Wills scale³. The flux density on this scale was obtained by multiplying values on the KPW scale⁴ by 1.23 at 178 MHz, 1.10 at 750 MHz and 1.06 at 1.4 GHz. No adjustment was made at frequencies of 2.65 GHz and above since the difference between the Wills scale, the KPW and other commonly used scales is small (less than 5%).

Measurement details of the new observations are as follows: **Algonquin.** Measurements with the 46-m Algonquin telescope were made on OH471 and OQ172 at 10.7 GHz between April and December 1973, and at 22.2 GHz during February 1974. The ARO 10.7-GHz receiver has a noise temperature of 120 K and a bandwidth of 100 MHz. The 22.2-GHz receiver has a noise temperature of 200 K and a bandwidth of 500 MHz. The observations were made by Andrew, Gearhart, Purton, Feldman and Marsh.

Bonn. Measurements were made with the 100-m telescope in July 1973 at 10.7 GHz and in August 1973 at 1.42 GHz with the results given in Table 1. Observers included Thiel, Fürst and Hirth.

Cambridge. The flux densities of both OH471 and OQ172 are below the 4C limit of 2.0 Jy at 178 MHz but an examination of the interferometer records yielded the values given in Table 1. In addition flux density measurements at 5.0 GHz of OH471 were made in June and July 1973 and of OQ172 in August 1973 and March 1974 with the 5-km telescope (Table 1) and accurate positions determined (Table 2).

Grakovo. Flux density measurements on OH471 and OQ172 were made during 1973 at decametric wavelengths with the (Ukrainian) UTR-2 radio telescope. This telescope consists of two arrays of wideband horizontal dipoles arranged in the form of a 'T'. One array, oriented north-south, is 1,860 m long and has 1,440 dipoles. The other, or east-west, array is 900 m long and has 600 dipoles. The array operates over the frequency range 10 to 25 MHz in a five-beam mode.

Observations on OH471 and OQ172 with the UTR-2 telescope showed no detectable signal from which it may be concluded that the flux density of both sources is less than 10 Jy (f.u.) at 16.7 MHz and less than 5 Jy at 25 MHz. These observations support the conclusion that neither source has

a low frequency component. The minimum detectable flux density is necessarily large because of confusion effects combined with the high sky background temperature ($\sim 10^5$ K).

Green Bank. Observations were made at 1.4 and 2.695 GHz with the 300-ft meridian transit telescope, using multiple-feed systems to determine accurate declination pointing corrections. The procedure has been described by Bridle *et al.*⁵. At 1.4 GHz, OQ172 was observed in February 1970 and OH471 in May 1973. At 2.695 GHz, OQ172 was observed in January 1973 and both QSOs were observed in April, May, and June 1973. Observations with the three-element interferometer were made in February 1974 at 2.695 and 8.085 GHz. The 300-ft telescope measurements were made by Bridle and the three-element interferometer measurements by Warner, Assousa, and Balick.

Kitt Peak. Observations at 31.4 and 85.3 GHz were made with the 11-m telescope at Kitt Peak during six days in March 1973 on OH471 and on four days in July 1973 on both OH471 and OQ172. Techniques were similar to those described by Conklin *et al.*⁶.

Itapetinga. Observations were made during July and August 1973 and again in February 1974 with the Mackenzie University (Brazil) 13.7-m radome-enclosed telescope at 22.2 GHz. The receiver bandwidth is 100 MHz and the system temperature about 2,500 K. A double beam feed was used consisting of two horizontally polarised horns with beam separated in the sky by 9° . The data were corrected for atmospheric absorption and radome attenuation.

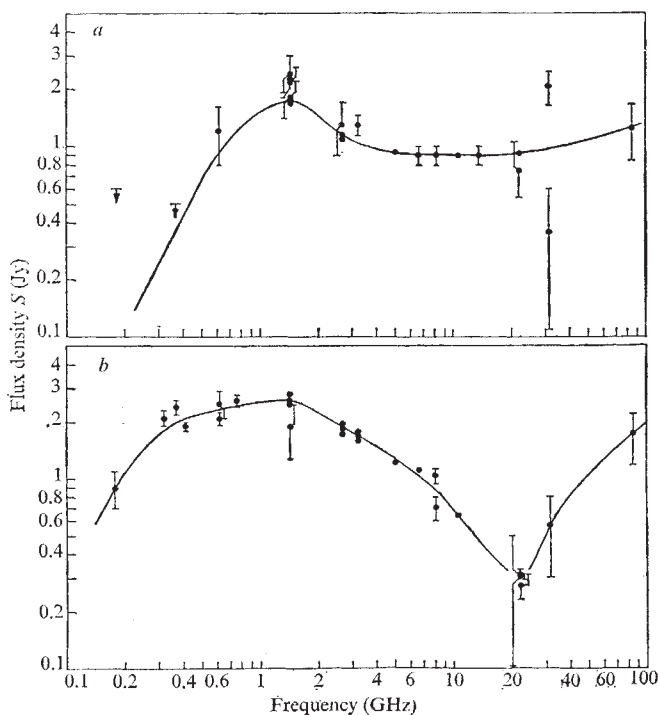


Fig. 1 Flux density (S) of OH471 (a) and OQ172 (b) against frequency. The points with no error bars have errors within the extent of the solid circle.

Measurements were made on seven days between July 25 and August 3, 1973, and on seven days in February 1974, for OH471 and on four days between July 25 and 29, 1973, for OQ172. Each measurement averaged more than 2 h of observing time. The measurements on OH471 were difficult

Table 1a Flux densities for OH471

Frequency	Flux density (Jy)*	Epoch	Observatory†
16.7 MHz	<10.0	1973	Grakovo
25.0	<5.0	1973	Grakovo
178	<0.6	1962	Cambridge
365	<0.5	1973-1974	Texas
612	1.2 (0.4)	1969.2-1970.2	Ohio ¹⁰
1.40 GHz	1.70 (0.07)	1973.41	Green Bank
1.415	2.4 (0.5)	1963.9	Ohio
1.415	2.3 (0.4)	1966.8	Ohio
1.415	2.2 (0.4)	1969.6	Ohio
1.415	2.2 (0.4)	1970.2	Ohio ¹¹
1.415	2.3 (0.4)	1970.2	Ohio
1.42	1.73 (0.07) a	9 Aug. 73	Bonn
1.42	1.73 (0.07) a	12 Aug. 73	Bonn
1.42	1.8 (0.4)	1974.0	Ohio
2.65	1.3 (0.4)	1969.7	Ohio ¹⁰
2.695	1.16 (0.03)	1973.28	Green Bank
2.695	1.10 (0.03)	1973.65	Green Bank
2.695	1.09 (0.05)	1974.1	Green Bank
3.2	1.30 (0.15)	1971.0	Algonquin ¹²
5.0	0.945(0.025)	8 Jun. 73	Cambridge
5.0	0.945(0.025)	19 Jun. 73	Cambridge
5.0	0.951(0.025)	2 Jul. 73	Cambridge
5.0	0.927(0.025)	24 Jul. 73	Cambridge
6.6	0.90 (0.10)	1971.2	Algonquin ¹²
8.09	0.90 (0.10)	1974.1	Green Bank
10.7	0.90 (0.10)	16 Apr. 73	Algonquin
10.7	0.95 (0.05)	22 May 73	Algonquin
10.7	0.81 (0.08)	25 Jun. 73	Algonquin
10.7	1.05 (0.11)	26 Jun. 73	Algonquin
10.7	0.87 (0.04)	27 Jun. 73	Algonquin
10.7	0.92 (0.04)	28 Jun. 73	Algonquin
10.7	0.88 (0.04)	29 Jun. 73	Algonquin
10.7	0.90 (0.04)	30 Jun. 73	Algonquin
10.7	0.88 (0.04)	1 Jul. 73	Algonquin
10.7	0.84 (0.04)	3 Jul. 73	Algonquin
10.7	0.89 (0.10)	24 Jul. 73	Algonquin
10.7	0.95 (0.14)	26 Jul. 73	Stanford
10.7	0.91 (0.04) b	26 Jul. 73	Bonn
10.7	0.87 (0.04) b	27 Jul. 73	Bonn
10.7	0.91 (0.04) b	28 Jul. 73	Bonn
10.7	1.01 (0.10)	24 Aug. 73	Algonquin
10.7	0.91 (0.10)	16 Sept. 73	Algonquin
10.7	0.92 (0.10)	12 Dec. 73	Algonquin
13.5	0.90 (0.10)	1971.2	Algonquin ¹²
22.2	0.70 (0.25)	25 Jul.-3 Aug. 73	Itapetinga
22.2	0.80 (0.20)	19-27 Feb. 74	Itapetinga
22.2	0.87 (0.09) c	3 Feb. 74	Algonquin
22.2	0.91 (0.06) c	4 Feb. 74	Algonquin
22.2	0.90 (0.08) c	5 Feb. 74	Algonquin
22.2	0.89 (0.09) c	5 Feb. 74	Algonquin
22.2	1.01 (0.06) c	6 Feb. 74	Algonquin
22.2	0.89 (0.07) c	7 Feb. 74	Algonquin
22.2	1.02 (0.09) c	8 Feb. 74	Algonquin
22.2	0.89 (0.07) c	9 Feb. 74	Algonquin
22.2	0.83 (0.12) c	10 Feb. 74	Algonquin
22.2	0.95 (0.08) c	13 Feb. 74	Algonquin
22.2	1.10 (0.15) c	13 Feb. 74	Algonquin
22.2	0.87 (0.10) c	14 Feb. 74	Algonquin
22.2	1.00 (0.12) c	18 Feb. 74	Algonquin
22.2	0.86 (0.10) c	18 Feb. 74	Algonquin
31.4	2.07 (0.4) c	8 Mar. 73	Kitt Peak
31.4	0.36 (0.25)	11 Mar. 73	Kitt Peak
31.4	1.79 (0.5)	12 Mar. 73	Kitt Peak
31.4	0.77 (0.35)	13 Jul. 73	Kitt Peak
31.4	0.21 (0.7)	14 Jul. 73	Kitt Peak
85.3	0.5 (1.1)	3 Mar. 73	Kitt Peak
85.3	1.5 (0.6)	4 Mar. 73	Kitt Peak
85.3	0.65 (0.9)	5 Mar. 73	Kitt Peak
85.3	1.25 (0.4)	3, 4, 5 Mar. 73(av.)	Kitt Peak
85.3	0.85 (0.7)	17 Jul. 73	Kitt Peak

* 1 Jy = 10^{-26} W m⁻² Hz⁻¹. Relative to Wills scale³.
a, relative to 3C147=23.3 Jy; b, relative to 3C147=4.14 Jy;
c, relative to DR21=17.8 Jy (peak with 1'.4 HPBW)
† Observations reported here, except where reference cited.

because of the low elevation angle of the source (less than 21°).

Ohio. Records stored in the Ohio State University (OSU) Radio Observatory archives for epochs as early as 1963 were used to obtain flux densities for OH471; records back to 1966 were examined for data on OQ172. The observations were made with the OSU radio telescope with techniques as given by Fitch *et al.*⁷. Further observations of OH471 were made at 1.42 GHz with the OSU radio telescope in January 1974.

Stanford. The aperture synthesis interferometer was used during July 1973 for measurements at 10.7 GHz. Both sources were unresolved indicating that their angular diameters must be less than 10''.

Texas. The Broadband Synthesis Interferometer (BSI) was used to search for OH471 at 365 MHz on two occasions during May 1973 and on five occasions during January 1974. It was not found, but assuming that the source is constant at 365 MHz the upper limit is 0.5 Jy with 95% confidence. Techniques are similar to those described by Ghigo and Owen⁸.

Table 1b Flux densities for OQ172

Frequency	Flux density	Epoch	Observatory
16.7 MHz	<10.0	1973	Grakovo
25.00	<5.0	1973	Grakovo
178	0.9 (0.2)	1966	Cambridge
318	2.1 (0.2)	1970	Arecibo ¹³
365	2.4 (0.2)	1972	Texas ⁸
408	1.9 (0.1)	1971	Molonglo ¹⁴
606	2.1 (0.15)	1970	Arecibo ¹³
612	2.5 (0.4)	1967.7	Ohio
750	2.6 (0.2)	1969.70	Green Bank ¹⁵
1.40 GHz	2.78 (0.06)	1969.70	Green Bank ¹⁵
1.40	2.58 (0.03)	1970.16	Green Bank ¹⁵
1.415	1.90 (0.6)	1966.5	Ohio
1.415	2.2 (0.5)	1967.7	Ohio
1.415	2.6 (0.5)	1967.7	Ohio ⁷
1.42	2.50 (0.08) d	12 Aug. 73	Bonn
2.65	1.70 (0.5)	1967.7	Ohio ¹⁶
2.695	1.96 (0.1)	1970	Nancay ¹⁷
2.695	1.85 (0.03)	1973.06	Green Bank
2.695	1.72 (0.06)	1973.28	Green Bank
2.695	1.81 (0.04)	1973.65	Green Bank
2.695	1.79 (0.05)	1974.1	Green Bank
3.2	1.60 (0.15)	1969	Algonquin ¹⁶
3.2	1.78 (0.04)	1970.08	Algonquin ¹⁵
3.2	1.74 (0.03)	1970.43	Algonquin ¹⁵
5.0	1.22 (0.1)	1970	Green Bank ¹⁷
5.0	1.22 (0.02)	Aug. 73-Mar. 74	Cambridge
6.6	1.10 (0.1)	1969	Algonquin ¹⁶
6.6	1.12 (0.03)	1969.76	Algonquin ¹⁵
6.6	1.12 (0.03)	1970.37	Algonquin ¹⁵
8.0	1.05 (0.10)	1971	Michigan
8.085	0.70 (0.10)	1974.1	Green Bank
10.7	0.70 (0.10)	1969	Algonquin ¹⁶
10.7	0.75 (0.05)	1969.19	Algonquin ¹⁵
10.7	0.51 (0.03)	1970.50	Algonquin ¹⁵
10.7	0.70 (0.07)	25 Jun. 73	Algonquin
10.7	0.54 (0.06)	26 Jun. 73	Algonquin
10.7	0.62 (0.04)	27 Jun. 73	Algonquin
10.7	0.66 (0.07)	2 Jul. 73	Algonquin
10.7	0.70 (0.08)	19 Jul. 73	Stanford
10.7	0.62 (0.02) e	25 Jul. 73	Bonn
10.7	0.62 (0.02) e	27 Jul. 73	Bonn
22.2	0.30 (0.20)	25-29 Jul. 73	Itapetinga
22.2	0.31 (0.09) c	4 Feb. 74	Algonquin
22.2	0.31 (0.03) c	5 Feb. 74	Algonquin
22.2	0.30 (0.03) c	6 Feb. 74	Algonquin
22.2	0.32 (0.04) c	7 Feb. 74	Algonquin
22.2	0.27 (0.04) c	16 Feb. 74	Algonquin
31.4	0.56 (0.25)	13-14 Jul. 73	Kitt Peak
85.3	1.73 (0.55)	16 Jul. 73	Kitt Peak

d, relative to 3C298=5.95 Jy; e, relative to 3C298=1.03 Jy. Otherwise as Table 1a.

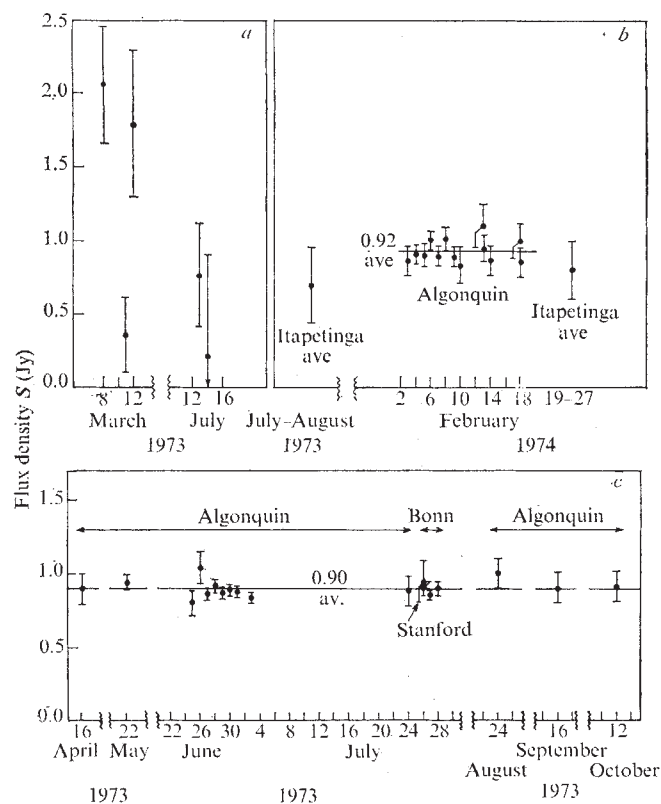


Fig. 2 Flux density of OH471 as a function of date for frequencies: 31.4 GHz(a), 22.2 GHz(b), and 10.7 GHz(c). a, All Kitt Peak data; b and c as labelled.

The spectra of OH471 and OQ172, shown in Fig. 1, are complex. Both have a low-frequency cutoff. The cutoff is particularly sharp for OH471. Both have a peak near 1.4 GHz and (if OH471 is not varying at 31.4 GHz) both have a second peak near or above 85 GHz suggesting at least two components.

The measurements on OH471 at 31.4 GHz made at Kitt Peak are suggestive of variability. But the observations at 22.2 GHz made at Algonquin show no evidence of variability and the observations at Itapetinga at the same frequency are inconclusive (Fig. 2). No observations were reported from other observatories for dates on which variability was observed at Kitt Peak so there is no direct disagreement. But the stability and greater precision of the Algonquin results are statistically inconsistent with the variability suggested by the Kitt Peak results if OH471 is a frequently fluctuating erratic variable as the later results imply. A frequency of 22.2 GHz is close enough to 31.4 GHz that a noticeable change might be expected to occur at 22.2 GHz accompanying a large variation at 31.4 GHz.

Measurements of OH471 between April and December 1973 made at Algonquin, Bonn and Stanford are all consistent with a constant flux density at 10.7 GHz.

Records from OSU of OH471 at 1.415 GHz since 1963 (Table 1) show no significant change in flux density until 1970. But between 1970 and 1974 there is a marginally significant decrease. So there may be slight variability at 1.4 GHz on a time scale of years.

Table 2 Radio positions of OH471 and OQ172

Source	$\alpha(1950.0)$	$\delta(1950.0)$	Observatory
OH471	06 ^h 42 ^m 53. ^s 023(0.0005)	+44°54'30".89(0".05)	Cambridge (5-km telescope)
OQ172	14 ^h 42 ^m 50. ^s 479(0.010)	+10°11'12".35(0".15)	Cambridge (5-km telescope)

According to Andrew *et al.*⁹ there is a 90% or greater probability of sources with centimetre-excess spectra, like OH471 and OQ172, exhibiting radio variability. Variability is suggested in OH471 and it will be interesting to continue measurements of OQ172, particularly in the region 10 to 40 GHz, to find if any variability exists.

The spectrum of OQ172 (Fig. 1b) is complex. It would take four or five straight (power law) segments to give even a first order fit. The spectrum of OH471 is similarly complex and is further complicated by apparent variability at 31 GHz.

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New position of Cen X-3 from Copernicus

THE X-ray source Cen X-3 (3U1118-60) is part of a pulsating, eclipsing, binary system^{1,2}. The third Uhuru catalogue³ gives a best position for the source of α (1950) = 11 h 18 min 55 s, δ (1950) = $-60^\circ 19' 5''$ with a 90% confidence error box of area 7×10^{-4} deg². At present this X-ray source has not been positively identified with an optical counterpart although several candidates have been suggested—(refs 4–6 and L. Webster, unpublished).

The Mullard Space Science Laboratory experiment on the Copernicus satellite has been used to observe Cen X-3 primarily with a view to refining the position but also to observe eclipse transitions at energies lower than those observed by Uhuru. The instrumentation which has been described elsewhere⁷; contains three co-aligned X-ray detection systems. The first contains a grazing incidence telescope (nonfocusing flux collector) and proportional counter sensitive in the nominal energy range 1.4 to 4.2 keV with circular apertures defining fields of view of 10 arc min (large), 3 arc min (intermediate) and 1 arc min (small); the second is similar and is sensitive in the energy range 0.7 to 2.0 keV with apertures defining fields of view of 10 arc min (large), 6 arc min (intermediate) and 2 arc min (small); the third is a collimated proportional counter sensitive in the energy range 4 to 12 keV with a fixed aperture of 3° .

Cen X-3 was observed by Copernicus between 1900 UT on February 17 and 0200 UT on February 18, 1973. From 1900 UT to 2130 UT on 17 February the package was pointed at α (1950) = 11 h 19 min 1.2 s, δ (1950) = $-60^\circ 18' 41''$ using the large apertures on the two telescopes and the X-ray source was observed emerging from an eclipse. The data from the three detectors are shown in Fig. 1; the background has been subtracted in the manner described previously⁷. The effectiveness of this method of background subtraction is well illustrated between 0000 UT and 0200 UT on February 18 when the satellite was passing through the edges of the radiation belts and there are no signs of their effects on the 4 to 12 keV signal.

Figure 1 also shows that the lower energy X rays appear later. This effect was predicted by Schreier *et al.*² since they assumed the length of the transition was not due to an extended source but to an extended atmosphere around the occulting star. The present observations confirm this prediction of an extended atmosphere, clearly showing the 1.4 to 4.2 keV signal appearing more than an hour after the 4 to 12 keV signal. There is very little emission at 0.7 to 2.0 keV which reinforces the interpretation of an absorbing atmosphere being present.

Between 2130 UT on February 17 and 0200 UT on February 18 the 2U error box was observed using the intermediate apertures on the two telescopes. Seven points in the error box were chosen for observation with times of typically 20 integration periods (one integration period being 62.5 s). The points were separated by 2 arc min so there was considerable overlap using the intermediate fields of view and significant emission was observed in three of these overlapping fields of view. Simultaneously the high energy system monitored the source and Fig. 1 shows that during this time the intensity of the source varied by less than

10% in the energy range 4 to 12 keV. (The response across the 3° field of view of the high energy detector is approximately triangular and the correction due to the small pointing excursions is less than 2%). So we assume there were no significant variations in the intensity of the source on time scales of minutes during these observations. Since the efficiency profile of the telescope field of view is well known, an estimate of the most likely position for the source can be made using the ratios of the count rates in the overlapping fields of view for the 1.4 to 4.2 keV system. This best position is at α (1950) = 11 h 19 min 1.8 s and δ (1950) = $-60^\circ 20' 27''$.

The error box for this position contains two components. First, there is a component due to the counting statistics giving a rectangular box 40×50 arc s and, second, one due to pointing uncertainties, of 10×20 arc s. The latter is derived from repeated observations of Sco X-1 which has a position known to better than 1 arc s. Combining these two sources of error gives a 90% confidence error box with corners shown in Table 1.

Table 1 Corners of error box for Cen X-3

	h	min	s		°	'	''
α (1950) =	11	19	1.1	δ (1950) =	-60	19	49
	11	19	7.1		-60	20	11
	11	19	3.7		60	21	5
	11	18	57.7		-60	20	43

These positions are shown schematically in Fig. 2 with the 90% error box from the 3U catalogue³. These error boxes marginally overlap, the Copernicus error box being much smaller (2.4×10^{-4} deg²) and more to the south-east.

Several optical candidates have been suggested for Cen X-3 and it is worthwhile examining these in the light of this new X-ray position. Margon and Wray⁴ have suggested WRA795, α (1950) = 11 h 18 min 56 s, δ (1950) = $-60^\circ 15' 48''$, but this can be definitely eliminated as being over 5 arc min north of this new position. The $m_v = 15$ blue star suggested by Liller⁵, L in Fig. 2, has been questioned by van Genderen⁶ who found that the optical period of the star did not fit the X-ray period. This star lies well outside the Copernicus error box and hence can

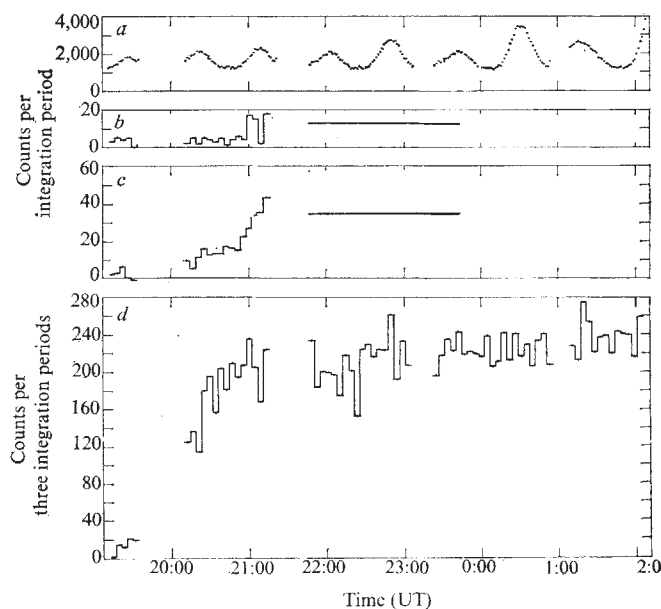


Fig. 1 Copernicus observations of Cen X-3 between 1900 UT on 17 February and 0200 UT on 18 February, 1973. Note the de-eclipse of the X-ray source between 1930 UT and 2100 UT. Integration period = 62.5 s, dead time between integration periods = 23 s. a, Charged particle background; b, 0.7 to 2.0 keV X rays; c, 1.4 to 4.2 keV X rays; d, 4 to 12 keV X rays.

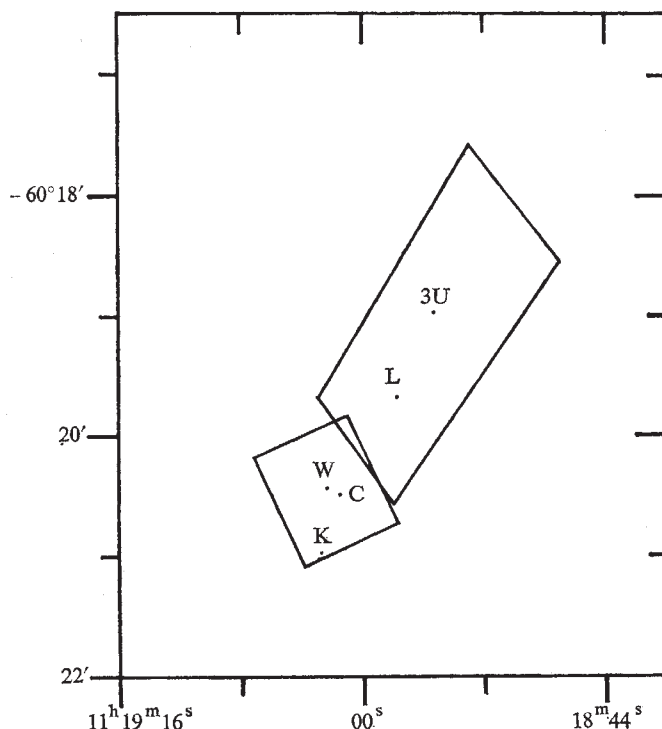


Fig. 2 X-ray error boxes for Cen X-3. C, Copernicus best position; 3U, Uhuru best position³; L, W, K, see text. K is the suggested position for Cen X-3.

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Interpretation of double structure in the celestial γ -ray bursts

THE essentially isotropic distribution of the Vela satellite γ -ray bursts¹ implies that the sources are either very local and galactic, or very remote and extragalactic. Of the theories for a remote origin there are two schools of thought, either that these γ -rays originate in shock waves during the formation of type II supernovae² or that they represent transient pulses of blackbody emission associated with the collapse of a white dwarf to a neutron star³.

A problem common to both of these theories is that they do not readily account for the fact that most of the observed bursts are double, and that the second pulse is frequently comparable in magnitude to the first.

I here make the suggestion that perhaps the sources of these γ -ray bursts may be identified with the collapse of a rotating magnetised star, following a model of the type computed by LeBlanc and Wilson⁴. In this model, at the later stages in the collapse, axial jets are formed in ~ 2.5 s which, in their specific example, carry energies $\sim 10^{51}$ erg at a temperature of $\sim 3.5 \times 10^9$ K, comparable to those estimated and required in ref. 3. The main objective of this suggestion is that if acceptable theoretically it could readily account for the double pulses.

Figure 1 represents a replot in polar coordinates of the density profile of Fig. A2a in ref. 4 at $t=2.67$ s and $\rho=3 \times 10^6$ g cm⁻³. Let θ be the angle of tilt between the rotation axis of the source and a perpendicular to the source-Earth line and let ϕ be the corresponding azimuth angle, ϕ being zero in Fig. 1.

If now the observed γ -ray bursts originate from such collapsing objects whose axes are randomly distributed, the following predictions are made:

(1) The pulses will in general be double, for radiation will be observable from both polar jets. (2) The delay time T between the two pulses will in general increase with τ , the duration of the individual pulses. (3) Single pulses will arise for all

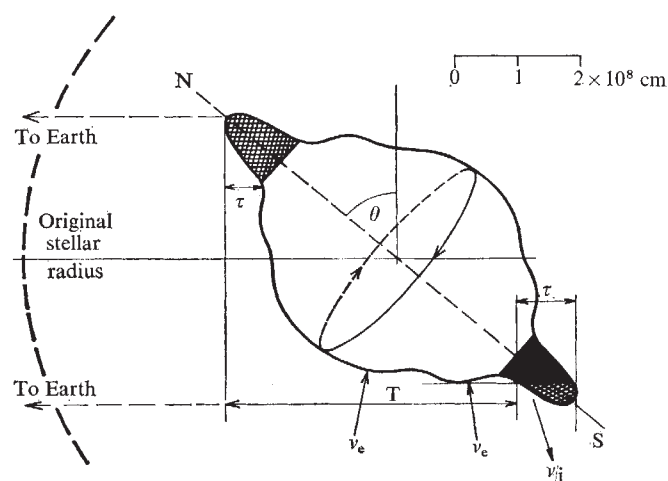


Fig. 1 Diagram to illustrate the active polar regions on a collapsing rotating star with an axial magnetic field, from LeBlanc and Wilson⁴.

be eliminated. Webster (unpublished) has suggested CPD $-59^\circ 3380$ (star 14 in Fig. 1 of ref. 9) marked W in Fig. 2. This star is an early B giant, and so may have insufficient mass to be the primary of the system. Krzeminski⁶ has found optical intensity variations, which seem to have a period equal to the X-ray period, in the $m_v \approx 13$ red star (K in Fig. 2). This star has been classified as an 09.5-BO.5 Ib star^{10,11} and so has sufficient mass to agree with the calculation of Schreier *et al.*²

Both of these last two stars are inside the Copernicus error box. However, the evidence presently available indicates that the star suggested by Krzeminski at $\alpha(1950) = 11 \text{ h } 19 \text{ min } 03 \text{ s}$, $\delta(1950) = -60^\circ 21' 00''$, is the optical counterpart for the primary of the Cen X-3 system.

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values of ϕ when $\theta=0$, for all values of θ when $\phi=\pi/2$, and if one or other of the jets is totally obscured by the equatorial regions of the collapsing star. (4) The first pulse will always be the stronger—because a larger fraction of the nearer jet is visible to the observer than the farther jet and because Doppler shifts of radiation from matter moving along the jets, resolved along the line of sight, will increase both the flux and the photon energy of the radiation from the nearer jet; and if some or all of the radiation is nonthermal, one might expect it to be directed predominantly along the jet. (5) There should never be more than two pulses.

The duration of the pulses τ will be compounded of the growth time and axial development of the jets, the rate of radiation production and the time difference corresponding to the line of sight path difference between the tip and the base of the 'visible' portion of the jet.

I now look at these predictions in the light of the data. Of the latest list⁵ of Vela events I find, in support of prediction (1) above, that of the 19 events for which information on the character of the pulses is presented, 12 are double. Figure 2 shows a plot, for these double events, of the duration τ of the first pulse with respect to the separation T between the pulses (presumed to be measured from the onset of the pulses). The event numbers on the plot correspond to those used in ref. 5. It is at once apparent that τ increases steadily with T , in agreement with prediction (2). I find seven pulses which are single, consistent with (3), five being wide (≥ 1 s) and two narrow (< 1 s). The wide pulses may correspond to overlapping of bursts from the individual jets or to relatively slow axial development of the jets. In support of prediction (4) I note that for the double pulses the first component is the larger in all cases, with the possible exception of event 71-2, for which the description is ambiguous. Regarding the multiplicity, prediction (5), the only event which reveals more than two pulses is 72-4, with a third event at $T=28$ s.

Regarding the intensity of the thermal radiation from the poles in the LeBlanc-Wilson model, the quoted mass and temperature of the jets, $\sim 10^{32}$ g and $\sim 3 \times 10^9$ K respectively, are sufficiently close to the corresponding values in ref. 3 that the γ -ray yields, and hence the distance-range of the sources (~ 25 to 300 Mpc) will be comparable on the two models.

A crucial question is whether the jets can penetrate the residual stellar envelope, to densities at which the medium is optically thin to ~ 100 keV γ rays, and in this connection it would be of interest to know: (a) how the strength, temperature and axial development of the jets in this model change by varying the input parameters; (b) the subsequent history of the jets beyond $t=2.67$ s, at which their calculations were

halted; and (c) what effects the axial magnetic field may have on the cooling time. The absolute time scales present a problem. On the specific model in ref. 4, the tips of the jets are $\sim 7 \times 10^8$ cm apart at $t=2.67$ s, so that for $\theta=60^\circ$, $T \sim 0.02$ s, a pulse spacing less than that measured for the shortest double event, Los Alamos burst No. 69-1. To obtain pulse separations of several seconds, reported in ref. 5, as well as by others⁶, we require that the post-collapse dimensions be far larger. We therefore ask whether Colgate's larger Type II $30M_\odot$ stars², with initial radii 10^{12} to 10^{14} cm can on collapse also develop axial jets, which could then radiate thermally at the required temperatures.

Finally some remarks on the fine structure. There seems to be no difficulty in explaining quite large intensity fluctuations within the framework of these ideas. There will be temperature fluctuations in the jets and fluctuations in the opacity of the outer regions of the envelope; these fluctuations will appear rapid to the observer, since the velocity vectors v_j and v_e of the jet and envelope respectively (Fig. 1) have opposite sign, see also Figs A6 in ref. 4.

It had previously been suggested³ that the secondary pulses and the fine structure could be interpreted as due to the rebound of the neutron star and/or its subsequent oscillations. This, however, would seem rather unlikely, as one would expect the primary catastrophic implosion, in view of its vast energy release, to outweigh by far the secondary effects, so that the γ rays from the latter would be expected to be relatively much less intense, by perhaps some orders of magnitude, and hence below the threshold of the existing detectors.

A more thorough check on these ideas will be possible when the structure curves of the individual bursts are available.

While the LeBlanc-Wilson model on which these ideas are based may be rather too specialised, it seems likely that any kind of outward-propagating shock wave in a star which is significantly rotationally flattened, would give rise to two hot spots on the surface and therefore a double burst.

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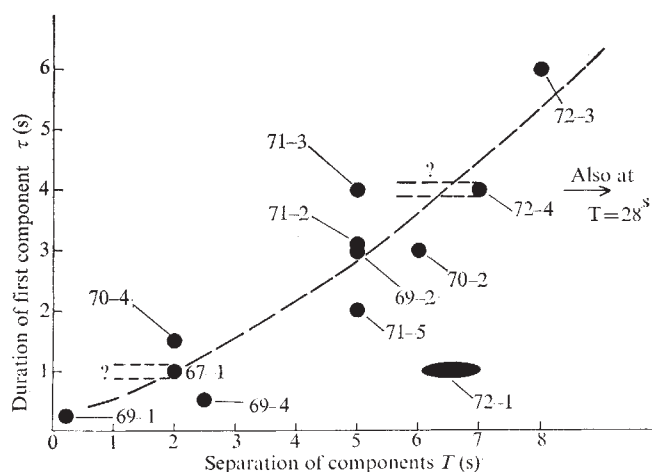


Fig. 2 A plot of the duration τ of the first component of all double pulses listed in ref. 5, with respect to the separation T between the two components.

Fifteenth-order harmonics in the geopotential

THE Earth's gravitational potential is usually expressed as a double infinite series of spherical harmonics. Analysis of thousands of photographic and laser observations of satellites, together with gravity measurements has yielded global models of the geoid¹⁻³ accurate to about 3 m on average. The harmonic coefficients have been evaluated complete up to degree and order 16 in the Goddard Earth Models (GEM) 4 and 6 (refs 1 and 2), and up to degree and order 18 in the Smithsonian Standard Earth III(SSE)³. Models currently being evaluated will extend to degree 25 (D. E. Smith, personal communication). Although these comprehensive global solutions give the overall geoid shape or gravitational field quite accurately, the individual harmonic coefficients of order between 10 and 20 are poorly determined among the matrix of 300 or more coefficients, and accurate methods for evaluating coefficients of a particular order are badly needed.

One of the best methods is to analyse the changes in the orbital elements of Earth satellites which pass slowly through a resonance with the Earth's gravitational field, when the ground track repeats after an integral number of revolutions. The 15th-order resonance, when the successive equator crossings are 24° apart and the track is repeated after 15 revolutions, is particularly useful because 15th-order resonant satellites circulate at heights near 500 km, where air drag is strong enough to ensure that the orbit contracts substantially in the course of a year. Consequently, each year many satellites experience 15th-order resonance as their orbits contract, and some of them pass through the resonance quite slowly, so that the orbital perturbations which result from 15th-order harmonics will build up^{4,5}. These perturbations can be analysed to determine 15th-order coefficients in the geopotential.

The longitude-dependent part of the Earth's gravitational potential at an exterior point (r, θ, λ) may be written in normalised form⁶ as

$$(\mu/r) \sum_{l=2}^{\infty} \sum_{m=1}^l (R/r)^l P_l^m(\cos \theta) [\bar{C}_{lm} \cos m\lambda + \bar{S}_{lm} \sin m\lambda] N_{lm}$$

where r is distance from the Earth's centre, θ is colatitude, λ is longitude (positive to the east), μ is the gravitational constant for the Earth ($398,601 \text{ km}^3 \text{ s}^{-2}$), R is the Earth's equatorial radius (6,378.1 km), $P_l^m(\cos \theta)$ is the associated Legendre function of order m and degree l , and $\bar{C}_{lm}$ and $\bar{S}_{lm}$ are the normalised tesseral harmonic coefficients which is to be evaluated (for $m = 15$). The normalising factor N_{lm} is given by⁶

$$N_{lm}^2 = 2(2l+1)(l-m)!/(l+m)!$$

For nearly circular orbits passing through 15th-order resonance, the rate of change of orbital inclination, $\dot{i}$, is proportional to $\dot{\Phi}(\bar{C}_{15} \sin \Phi - \bar{S}_{15} \cos \Phi)$, where $\bar{C}_{15}$ and $\bar{S}_{15}$ are 'lumped' 15th-order coefficients⁷ and Φ is the 'resonance angle' (written as Φ_{15} in ref. 7), which becomes stationary at resonance. A computer program, THROE, has been developed⁷ to fit the observed variation of $\dot{i}$ with a theoretical curve which includes not only the terms in $\sin \Phi$ and $\cos \Phi$, but also terms in $\sin 2\Phi$, $\sin 3\Phi$, and so on, and terms involving the eccentricity, e , if these are appreciable.

The values $\bar{C}_{15}$ and $\bar{S}_{15}$ found from a particular orbit can be expressed as a linear sum of individual coefficients $\bar{C}_{l,15}$ and $\bar{S}_{l,15}$ of odd degree ($l = 15, 17, 19 \dots$). To determine these individual coefficients, values of C_{15} and S_{15} need to be found for orbits at a wide variety of inclinations. The first pair of values, determined by Gooding⁷ were from analysis of Ariel 3 (1967-42A) at inclination 80° . In 1972 King-Hele utilised the orbits of three further resonant satellites⁸ at inclinations of 51° , 62° and 74° , to evaluate the coefficients of order 15 and degree 15, 17, 19 and 21. We have now been able to analyse the orbits of another eight resonant satellites, at inclinations of 31° , 33° , 38° , 51° , 54° , 56° , 74° and 90° . From these and the previous orbits we have obtained values⁹ for the 15th-order coefficients of degree 15, 17, 19 ... 31.

Figure 1 shows the fitting for one of the 11 satellites, Cosmos 395 rocket (1971-13B), which is in a circular orbit at 74° inclination: this satellite is fairly typical, both in the accuracy of the fitting and in the magnitude of the effect. The main resonance oscillation has an amplitude of about 0.015° and the theoretical curve fits well¹⁰, giving values of $\bar{C}_{15}$ and $\bar{S}_{15}$ accurate to 4%.

From the 11 satellites we have derived 11 pairs of linear equations between the coefficients $\bar{C}_{l,15}$ and $\bar{S}_{l,15}$ ($l = 15, 17, 19 \dots$). To these equations we added a pair derived by Wagner and Klosko¹¹, and nine pairs of equations specifying constraints on the values of the coefficients given by Kaula's rule-of-thumb⁶ that the coefficient of degree l is likely to be of order $10^{-5} l^{-2}$. These 21 pairs of equations were then solved by least-squares, taking account of the correlations between $\bar{C}_{15}$ and $\bar{S}_{15}$, to determine nine pairs of values of the individual

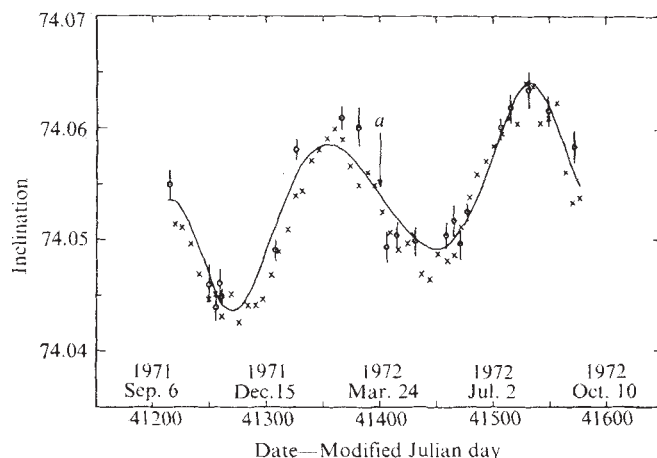


Fig. 1 Values of inclination at resonance of Cosmos 395 rocket (1971-13B), with fitted theoretical curve (—). Crosses, values from United States Navy orbits (s.d. taken as 0.003°); $\circ$, values determined at the Royal Aircraft Establishment from Hewitt camera, visual and United States Navy observations (s.d. shown as error bars); a, 15th-order resonance on March 24, 1972.

coefficients of 15th-order, from degree 15 up to degree 31 (Table 1).

Table 1 shows that the numerical values of the C coefficients, of which seven out of nine exceed 10^{-8} , are much larger than the S coefficients, of which only one exceeds 10^{-8} . In a sense this bias is a result of chance, because the choice of reference longitude for defining C and S (the Greenwich meridian) is arbitrary. The effect may, however, be geophysically significant, if the 15th-order S coefficients are small for all degrees.

Table 1 Values of $\bar{C}_{l,15}$ and $\bar{S}_{l,15}$

l	$10^8 \bar{C}_{l,15}$	$10^8 \bar{S}_{l,15}$
15	-21.5 ± 0.9	-8.4 ± 0.9
17	4.4 ± 1.6	9.0 ± 1.5
19	-15.6 ± 2.6	-14.1 ± 2.7
21	10.4 ± 3.0	7.3 ± 3.5
23	22.5 ± 2.8	1.2 ± 4.4
25	-0.9 ± 4.7	-3.8 ± 5.3
27	-11.2 ± 3.3	9.1 ± 3.2
29	-20.5 ± 5.4	-1.2 ± 6.1
31	17.7 ± 6.6	-1.0 ± 7.1

The last two S values (Table 1) are not significant, and their omission would reduce the standard deviation (s.d.) for the other values. They have to be included because of their correlations with the C values, but it is probable that the real errors in the S coefficients up to degree 27 are smaller than the given s.d.

Another feature of interest (Table 1) is that the C values, though larger than the S values, are still mostly less than the values indicated by the rule-of-thumb $10^{-5} l^{-2}$. Thus, the constraint equations used turn out to be quite weak, and the values of the individual coefficients are determined primarily by the 11 pairs of equations from the orbital analysis.

Finally, the rather large values of $\bar{C}_{29,15}$ and $\bar{C}_{31,15}$ indicate that the evaluation ought to be carried to a higher degree. We hope to do this after observation of further satellites passing through 15th-order resonance and analysis of their orbits. There is a particular need for results at orbital inclinations between 40° and 50° , and between 64° and 73° .

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High resolution α spectrometry

DEFICIENCIES in energy resolution have been an obstacle to the widespread application of dielectric track detectors¹. The best resolution so far obtained covered a span of only 150 to 200 keV (ref. 2). Now a procedure has been developed which uses the range differences obtained with α particles of diverse emission energies. This procedure provides a substantially improved energy resolution.

The pits, which are etched on to the front of dielectric track detectors, are a result of primary ionisation, and the diameter of each pit therefore provides a measure of energy. Unfortunately, however, the properties of the material used and the etching conditions also influence the diameter of the pits. At the onset of etching, particles have an entrance energy that is higher than the threshold energy. The onset is not very well defined because, near the threshold, the rate of track etching, V_t , differs only slightly from the rate of volume etching, V_b , of the intact material. This explains the low growth of etch pits in the initial phase. If, however, detector sheets are etched from the rear the onset of etching is sharply defined because, as the particle trajectory is approached, the density of radiation damage

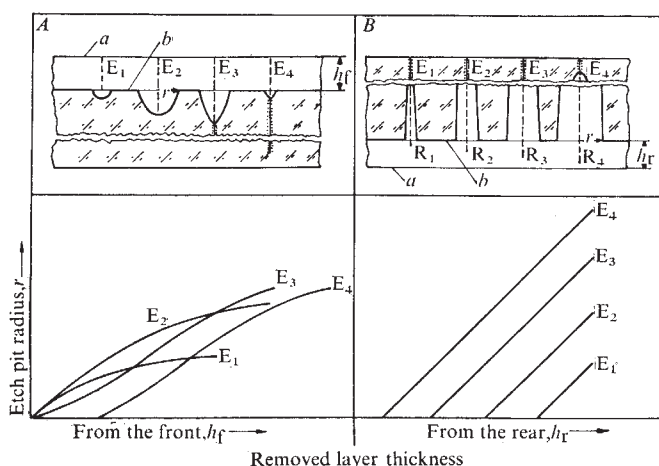


Fig. 1 Two methods of energy determination. The track evolution is shown as a function of the thickness of the removed surface: *A*, etching the frontside of a medium sensitive detector such as cellulose acetate leads to a dependence of the etch pit growth from the particle energy used for energy determination; *B*, etching the rear of a very sensitive detector perpendicularly irradiated with α particles of different energies results in a pit radius kinetic with a slope which is independent of the particle energy, in which the differences of the etch pit radii are equivalent to the range differences of the α particles. *a*, original surface; *b*, etched surface.

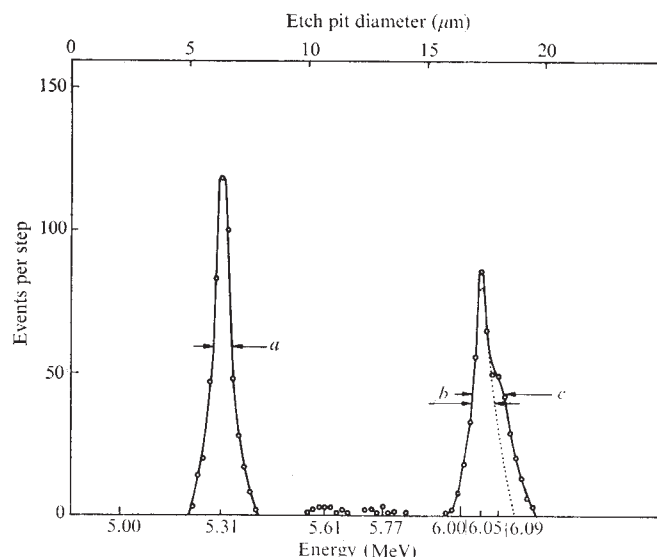


Fig. 2 Distribution of the etch pit diameters measured on the rear of a highly sensitive cellulose nitrate detector irradiated with α particles of ^{210}Po (5.31 MeV) and of ThC (5.61, 5.77, 6.05 and 6.09 MeV). *a*, 54 keV; *b*, 46 keV; *c*, 71 keV.

reaches a maximum. The radius of the etch pit produced then increases proportionally to the thickness of the surface removed from the rear (Fig. 1).

A necessary precondition of this method is that the α particles come to rest in the detector sheet. For maximum resolution, the particles must enter the detector normal to its surface, a condition which can be easily realised. If irradiation occurs under 2π geometry, only round etch pits with an accurate concentric configuration are evaluated. To obtain maximum energy resolution I have used very sensitive cellulose nitrate sheets³. In this detector even α particles create a very high track etch rate, so that immediately after the formation of an etch pit, the radius, r , will increase at the same rate as the volume etch rate. Up to a diameter of 25 μm no deviation from this relationship has been observed. Thus, we obtain the optimum condition $\Delta r = \Delta R$ that is, the difference in diameter of the etched tracks corresponds with twice the range difference, ΔR , of the α particles. With one-sided etching of the rear of the detector the particle range corresponds to the sum of the residual thickness and the etch pit radius. If the range-energy characteristic of the particles in the detector material is known, the energy of the particles can be determined.

To demonstrate the high degree of energy resolution of the new method a detector sheet of 38 μm was irradiated with α particles from a ^{210}Po source (5.31 MeV) and a ThC source (5.61 MeV), (1.1%), 5.77 MeV (1.8%), 6.05 MeV (68%) and 6.09 MeV (27%) at a pressure of 5×10^{-2} torr, with a distance of 50 mm between source and detector. The irradiated surface had a diameter of 1.5 mm. The rear of the sheet was then etched, using 30% KOH at 60°C until the thickness was reduced to 25.7 μm . All the emission energies from 5.31 to 6.09 MeV were thus obtained.

The determination of energy was based on the microscopic measurements, at each peak, of the diameters of 500 etch pits. Figure 2 shows the diameter distribution. The step width of the diameter determination was 0.25 μm . The full width at half maximum (FWHM) of the ^{210}Po peak was 54 keV, and the FWHM of the asymmetric peak of ThC was 71 keV. The peaks were at the 6.05 and 6.09 MeV emission energies. The FWHM of the 0.65 major peak was 46 keV. At lower emission energies, a drop in resolution caused by the increase in specific energy loss can be expected.

Using this method the energy resolution is influenced by the specific energy loss, the range straggling, the evenness of the sheet thickness, the etching process, and the microscopic

measurement. Specific energy loss and range straggling depend on the energy of the particle. The evenness of the sheet thickness has to be better than $\pm 0.2 \mu\text{m}$. Under the conditions described here the contribution of the etching process and the microscopic measurement amounts to 40 keV for the ^{210}Po peak and 33 keV for the ThC major peak.

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Eocene echinoids and the Drake Passage

AUSTRALIA and Antarctica separated about 50 million years (Myr) ago¹. Echinoid populations indicate a warmer climate at the time of separation than later. A model of oceanic circulation in the Southern Hemisphere, consistent with this observation, leads to a more precise dating of the opening of the Drake Passage between South America and Antarctica.

The oldest echinoid fauna known from the opening seaway between Australia and Antarctica has been preserved at several localities between Albany and Adelaide. The fauna is most abundant and best known in the Late Eocene Tortachilla Limestone, which outcrops along the eastern flank of the St Vincent Basin, south of Adelaide. Eighteen species of echinoids have been described from this formation of small lateral extent and a further five have yet to be described. The marsupiate echinoids, which are intermittently common in the Tertiary of southern Australia, are notably absent. Echinoids are also abundant a little further up the section at a Late Eocene horizon, low in the Port Willunga Beds. Less than 10 species are known at this level, and almost all are of genera different from those in the earlier Tortachilla. They include the earliest of the Australian marsupiate echinoids, the temnopleurid *Paradoxechinus stellatis* Philip and Foster.

A similar situation exists on the opposite flank of the basin. There is a complete change in the echinoid fauna between the Muloowurtie Formation and the overlying Rogue Formation in which *P. stellatis* appears.

By analogy with recent Antarctic brood-protecting echinoids, it has been inferred that the marsupium, developed in the female of several species of Australian Tertiary Temnopleuridae, Clypeasteroidea and Spatangoida, confers an advantage in colder water². An unsatisfactory aspect of correlating the presence of marsupiate echinoids with cold water is that the earliest fauna of the discussed region contains no marsupiate echinoids—despite the fact that this fauna probably lived more than 20° further south than its present position. Marsupiate echinoids are, in fact, a conspicuous component of the fauna during the journey of Australia towards the tropics.

Frakes and Kemp³ proposed a model of early Tertiary climates which may provide the answer. In the Eocene there was no circumpolar cold current in the Southern Ocean because of the presence of a continuous Andean–West Antarctic mountain chain. As Australia was far to the south of South-east Asia, ample room existed for the southern equatorial current of the Pacific to continue into the Indian

Ocean, sweep south and return, at least in part, through the new seaway which separated Australia from Antarctica. Because of the long time spent travelling through about 200° of longitude in the tropics, the equatorial current, which left the coast of South America at about 19° C, began its southerly sweep into the Indian Ocean at about 37° C. It was probably still above 20° C as it passed along the southern coast of Australia. A warm water echinoid fauna can therefore be expected. By the mid-Oligocene, the northward drift of Australia had restricted the flow of warm equatorial Pacific water into the Indian Ocean. More important, the breaching of the Andean–West Antarctic mountain barrier allowed a circumpolar cold current to replace the warm current in the widening seaway between Australia and Antarctica. The water temperature probably fell to well below 10° C. A changed echinoid fauna, including brood-protecting species, is consistent with this model.

Dalziel and Elliot⁴ estimate the opening of Drake Passage, and thus the beginning of the circumpolar current, to have occurred between the latest Cretaceous (65 Myr) and about 25 Myr ago.

The Tortachilla Limestone was deposited at the beginning of the Late Eocene, probably high in P15 in the planktonic foraminiferal zonation⁵. The Port Willunga Beds have been sampled and dated⁶ especially to provide a time framework for the sequence of echinoids, and the horizon containing *P. stellatis* has been placed high in the Late Eocene, corresponding to P17.

Using ages attributed to the planktonic foraminiferal datum planes⁵ as a guide, the event which caused the replacement of a warm water by a cold water echinoid fauna in the seaway between Australia and Antarctica can be dated at about 40 Myr—probably 41–36 Myr. This event was probably the inception of the mighty Antarctic circumpolar current, which began with the breaching of the Andean–West Antarctic Cordillera and the concomitant creation of the Drake Passage. Thus, there is indirect evidence which enables the separation of South America from Antarctica to be more precisely dated than before.

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Closing of the Protocadic Ocean and intraplate basins

THE presence of several long-lived, deeply subsiding basins, autogeosynclines¹, such as those in Michigan, Illinois, North Kansas and Williston suggests that the North American craton or plate remained in a constant position relative to the underlying mantle during the Palaeozoic.

In the Michigan Basin the Precambrian basement surface subsided about 4,000 m between the late Cambrian and the Devonian^{1–6}. Throughout this time, there was little deposition of terrigenous sediment and subsidence was largely independent of loading. With a few exceptions, the isopachs of many of the series and stages within the basin are centred to the west and north of Saginaw Bay, a little to the north-east of the centre of the structural basin⁷. However, during the mid-Ordo-

vician there was more subsidence in the south-east³, than elsewhere and during the early Silurian, the subsidence was suppressed, and carbonate reef belts extended along the northern and southern margins of the basin^{8,9}. The rates of subsidence, relative to periods of deformation in the Taconian–Acadian orogenic belt to the east, are not known. Other intraplate basins subsided differentially over long periods of time, but not to such great depths.

The subsidence of the Michigan Basin caused, or resulted in, the displacement of a great volume of crustal material. It is not known whether the Moho was depressed or even if it is still deeper than in surrounding areas. The origin of domes¹⁰ can be attributed to the expansion of crustal rocks above rising convection currents which heat the base of the crust. The formation of downward expanding convection cells is perplexing, but something like that occurred. The fact that the centre of subsidence was more or less fixed geographically seems to indicate that the crust did not move relative to the mantle under the North American plate. Therefore, the deep subsidence must have had a subcrustal cause.

It is believed that the ocean on the eastern margin of the North American craton resulted from the separation of the European and North American plates. It is usually called the 'proto-Atlantic' ocean¹¹, but I prefer to call it the Protacadic Ocean in reference to its closing during the Taconian–Caledonian–Acadian orogenies^{13,17}. It is not the progenitor of the present Atlantic, and the term 'proto-Atlantic' has been applied more logically to the opening of the present South Atlantic Ocean during the early Mesozoic. The Dunnage Melange in north-eastern Newfoundland formed in a subduction zone in which the oceanic plate passed beneath the North American plate to the north-west^{12,14}. Island-arc volcanics are represented in the Summerford Group to the north¹⁵. South of the Dunnage fault-bounded block, the Campbellton sequence of mafic volcanic rocks, manganiferous chert and greywacke flysch may represent ocean floor^{16,17} and the better displayed Snooks Arm Group farther west has been attributed to oceanic crust^{18,19}.

During the early Palaeozoic the European plate does not seem to have had any deep autogeosynclines like those in North America²⁰. The total subsidence of a trough through the middle of the European platform is only a tenth of that which occurred in the Michigan Basin over a similar time and there is no specific centre of sinking in this much larger area.

It is suggested that the autogeosynclines in the North American plate were linked to the underlying mantle, as is the case with modern plumes²¹. Both the plate and the mantle retained a fixed geographical position for about 100 Myr during the early Palaeozoic. The European plate moved over the mantle toward the North American plate, closing the Protacadic Ocean. The North American palaeomagnetic pole position for the Ordovician is very close to the Upper Palaeozoic position, which supports this hypothesis; however, it moved to lower latitudes during the Silurian, if the records are correctly interpreted²².

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Seismic refraction experiment on the Mid-Atlantic Ridge in the FAMOUS area

WE report results from ocean bottom seismographs (OBS)¹ and sonobuoys, in which unreversed refraction lines have been shot along and across the median valley of the Mid-Atlantic Ridge. P-wave arrivals indicate a structure under the median valley with layer 2 overlying 7.3 km s⁻¹ mantle. Under the mountains on the ridge crest P and S arrivals suggest that layer 2 overlies layer 3, which in turn overlies 7.3 km s⁻¹ mantle.

There are still relatively few determinations of the seismic velocity structure under the Mid-Atlantic Ridge^{2–4} and only one has been reported⁵ shot within the confines of the median valley. On geological grounds, Cann⁶ has proposed the existence of a magma chamber situated at the top of a rising column of the asthenosphere at a depth of 3–4 km beneath the median valley. Francis and Porter¹ suggested that the postulated magma chamber could account for seismological results at 45° N. Seismologists^{7–9} working with teleseismic data from earthquakes near the Ridge axis have reported a sharply bounded zone of low *Q* in the upper mantle beneath the axis, a 'gap in the lithosphere' across which *S_n* is not propagated.

A straight, but narrow section of the median valley bounded by fracture zones was chosen for this work and three OBS were laid, 10 km apart. Two were in the median valley and one on the mountains on the ridge crest to the east (Fig. 1). The tape recorder in OBS1 jammed, so no records were obtained from it. Three lines of near-surface shots were fired: A and B across the valley, perpendicular to the structure, and C along it. Line A (16 shots) was 37 km long, line B (16 shots) 36 km and line C (14 shots) 30 km. It was anticipated that the structure beneath the median valley would change near the fracture zones, so care was taken not to extend line C as far as them. For line C two recording sonobuoys were laid one mile apart straddling the position of OBS1, and for lines A and B two were laid, also one mile apart, over OBS3. The buoys drifted less than one mile from the laying position and during the shots along line C they stayed over the median valley the whole time.

Topographic correction is clearly necessary although a true scale section along lines A and B shows that the structure is not impossibly rugged. Arrivals have been corrected for a mean depth of 2.64 km (1,445 fathoms), assuming that the rock layering follows the sea floor. The times at the OBS and the sonobuoys have been corrected to the sea surface.

The results obtained by fitting least-squares straight lines to the first arrivals on the time distance diagrams are shown in Table 1. The weighted means of the apparent velocities are 4.91 ± 0.12 (layer 2), 6.64 ± 0.08 (layer 3) and 7.26 ± 0.06 ('mantle').

The data for both lines A and B from OBS3 and the sonobuoys fit together well when plotted on one time–distance

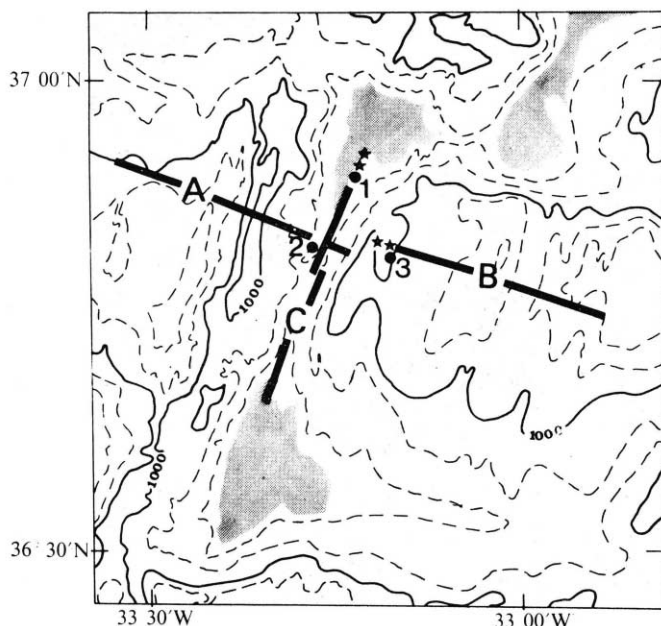


Fig. 1 Bathymetric chart showing the median valley, from an unpublished chart by J. D. Phillips, Woods Hole Oceanographic Institute. Contour interval 200 fathoms. Shaded areas are deeper than 1,500 fathoms. Dots, positions of OBS1, 2 and 3, stars, approximate positions of sonobuoys; Lines A, B and C, approximate track of ship during the firing of surface charges.

diagram, and the velocities and intercepts for the combined data for each line are within the limits of error of those obtained for the receivers treated separately. It is surprising that a similar statement applies to the sonobuoys and OBS2 for line C, considering that the receivers were 10 km apart. This suggests that the gross structure is more level, planar and homogeneous than may have been expected. No more than two refractors were detected on any line and the velocity and intercept of the upper one is not well determined and may be variable. Paths which cross the median valley, line A into OBS3, line B into OBS2, and line C, all detect a velocity of 7.3 km s^{-1} as the deepest refractor; paths which do not cross the median valley, line A into OBS2, and line B into OBS3, detect 6.6 km s^{-1} as the deepest refractor. The structure under the median valley is shown in Table 2a; it corresponds very well with the axial structure suggested by Le Pichon *et al.*². The fact that the layer 3 velocity, 6.6 km s^{-1} , was detected under the flanks of the Ridge, should be treated with caution because the lines were not reversed and lateral velocity changes are to be expected. The detection is, however, consistent with the work of Keen and Tramontini⁴ who found evidence of the presence of layer 3 within 20 km of the axis at 45° N .

Table 1 P-wave arrivals

Line	Receiver	Velocity* (km s^{-1})	Intercept* (s)	N
C	Sonobuoys and OBS2	5.17 ± 0.51	3.72 ± 0.13	11
		7.19 ± 0.09	4.37 ± 0.03	24
	Sonobuoys	4.21 ± 0.46	3.35 ± 0.21	5
		7.34 ± 0.09	4.45 ± 0.04	19
A	Sonobuoys and OBS3	5.09 ± 0.39	3.60 ± 0.12	12
		7.33 ± 0.17	4.45 ± 0.05	31
B	OBS2	7.42 ± 0.21	4.68 ± 0.10	12
		4.41 ± 1.13	3.50 ± 0.38	6
B	Sonobuoys and OBS3	6.75 ± 0.26	4.12 ± 0.11	6
		5.02 ± 0.36	3.59 ± 0.10	12
	OBS3	6.57 ± 0.17	3.99 ± 0.07	24

N is the number of points to which the line was fitted. Only the hydrophone traces from the OBS were used.

* Intercepts and velocities are quoted with their standard errors.

Table 2 Structures

	Line	Velocity (km s^{-1})	Thickness (km)
a	C Sonobuoy and OBS2	1.5	2.64
		[2.8]	0.58
		5.17	2.05
		7.19	
b	A OBS2	1.5	2.64
		[2.8]	0.35
		4.41	1.34
		6.75	
c	B Sonobuoy and OBS 3	1.5	2.64
		[2.8]	0.39
		5.02	1.20
		6.57	

Brackets enclose assumed velocities⁵.

Whitmarsh concludes, from shots at almost the same location as line C, that layer 3 is present at the ridge axis under the median valley⁵. This may be because the direct water wave arrival on his records has obscured the crossover between the 5.2 km s^{-1} and 7.2 km s^{-1} lines, causing him to fit just one line to these two sets of points. If one line is fitted to the 35 points on our time-distance diagram we obtain a velocity of $6.5 \pm 0.12 \text{ km s}^{-1}$ and an intercept time of $4.06 \pm 0.04 \text{ s}$, which is similar to Whitmarsh's result.

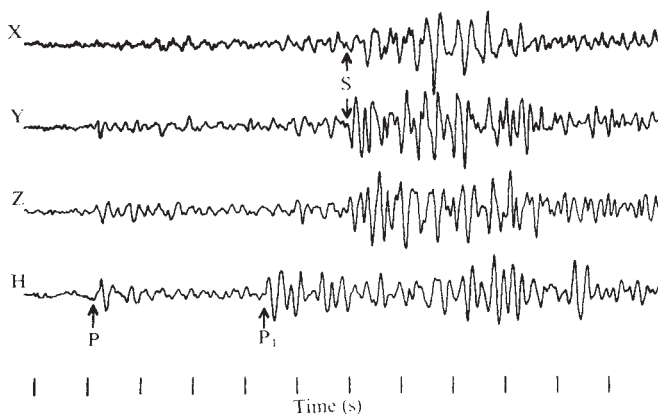


Fig. 2 Record from OBS2 of a shot on line B fired at a range of 36 km.

Table 3 Shear-wave arrivals

Line	Receiver	Velocity* (km s^{-1})	Intercept* (s)	N
C	OBS2	3.32 ± 0.63	4.16 ± 0.78	5
A	OBS3	3.96 ± 0.19	5.03 ± 0.31	8
B	PBS2	4.08 ± 0.13	5.49 ± 0.22	9
A	OBS2	4.03 ± 0.12	5.03 ± 0.13	7
B	OBS3	3.82 ± 0.64	5.11 ± 0.92	6

N is the number of points to which the line was fitted.

* Intercepts and velocities are quoted with their standard errors.

A typical record of S waves is shown in Fig. 2. Arrivals are visible on both OBS2 and OBS3 for shots fired at ranges greater than 10 km. The results of fitting least-squares lines to the data are shown in Table 3. It can be seen that there are no significant differences between them. The weighted mean velocity is $4.02 \pm 0.05 \text{ km s}^{-1}$. Model calculations using the structures suggested by the P-wave arrivals and assuming a V_p/V_s ratio of $\sqrt{3}$ indicate that the arrivals are consistent with waves transformed to a shear wave at the seafloor and propagated as a head wave in the 7.3 km s^{-1} layer. There is no evidence for a lower velocity on lines A into OBS2 and B into OBS3, on which the highest P-wave velocity was 6.7 km s^{-1} , which could

suggest that the 7.3 km s^{-1} layer underlies layer 3 there. Nor is there any evidence for a velocity of about 2.8 km s^{-1} , corresponding to shear waves propagating in layer 2.

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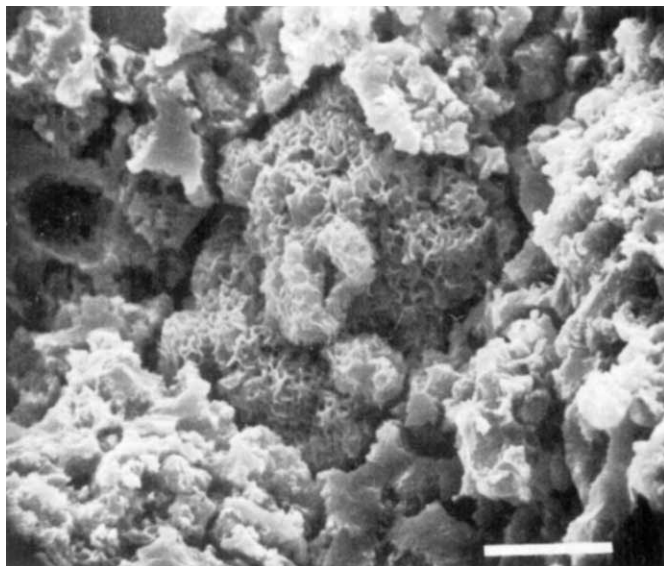


Fig. 1 Rosettes of hydrous mica filling the pores in porcellanite (opal-CT). SEM photomicrograph. Scale bar, $10 \mu\text{m}$.

Clays and formation of deep-sea chert

CHERT in the Pacific, Atlantic, Indian and Southern Oceans occurs both as nodules and as layers or lenses¹. Associated sediments include carbonate, biogenous silica, brown clay and volcanic ash. Chert is usually found in Middle Eocene or older sediments; the actual time of chert formation is, however, not known.

Biogenous opal is the principal source of silica for the formation of chert^{1,2}. Silica may also be produced by the alteration of volcanic detritus, resulting in the mineral assemblage smectite, zeolite and opal^{3,4}. A third possible source, not previously suggested in the literature, is the submarine diagenesis of clay minerals. Alteration of a smectite to hydrous mica or chlorite would release silica. The formation of secondary chert by the subaerial transformation of a ferric-rich smectite to kaolinite has been described by Altschuler *et al.*⁵, and several studies have shown that hydrous mica (illite) and chlorite become dominant at the expense of other clay minerals with increasing age⁶.

A 9-meter piston core (Scan 16P) taken from a depth of 5,597 m, $16^\circ 25' \text{N}$ $164^\circ 24' \text{W}$, containing a stiff, homogeneous, brown zeolitic clay with a porcellanite layer at 436 cm, has been studied. The age of the sediment was determined from radiolaria to be Middle Eocene. Seismic profiles from the area show an upper, probably chert, reflector at 30–40 m.

The brown clay has a sharp contact with the porcellanite layer and was identified by X-ray diffraction as smectite with minor hydrous mica. Using the X-ray diffraction opal classification of Jones and Segnit⁷, the radiolaria are opal-CT with quartz, and the porcellanite is opal-A and opal-CT. Optically, the quartz is chalcedony and forms internal moulds of radiolaria tests.

Scanning electron microscope examination revealed that the outer borders of the porcellanite layer have a botryoidal surface, composed of opal-A and radiating needles of opal-CT. Internally, the porcellanite layer is porous, massive opal-CT, with clay rosettes within the pores (Figs 1 and 2).

Using a transmission electron microscope, an electron diffraction pattern of a well crystallised clay particle was obtained. The d spacings of the clay were calculated from several diffraction patterns (4.46 (020,110), 3.30 (022,003), 2.59 (200,131), 2.32 (201,132), 1.97 (005), $1.48 (060,331) \pm 0.05 \text{ \AA}$) and closely matched those of hydrous mica^{8,9}.

Evidence which suggests that the mineral is a hydrous mica was also obtained with the electron microprobe. A traverse across a fracture surface of the porcellanite, measuring the presence and relative abundance of aluminium and potassium in the blue luminescent clay gave the results shown in Fig. 3, and the ratio of silicon to aluminium was measured as 1.2. No magnesium, and only a trace of iron, was detected in the clay. A sample of the smectite from the surrounding sediment was also analysed and had a substantially higher silicon to aluminium ratio of 3.4 and a magnesium to iron ratio of 0.8.

The dominant clay mineral in the surrounding sediment is a magnesium-iron smectite and in the porcellanite layer it is a hydrous mica. This distribution, in conjunction with the evidence discussed, suggests a relationship between

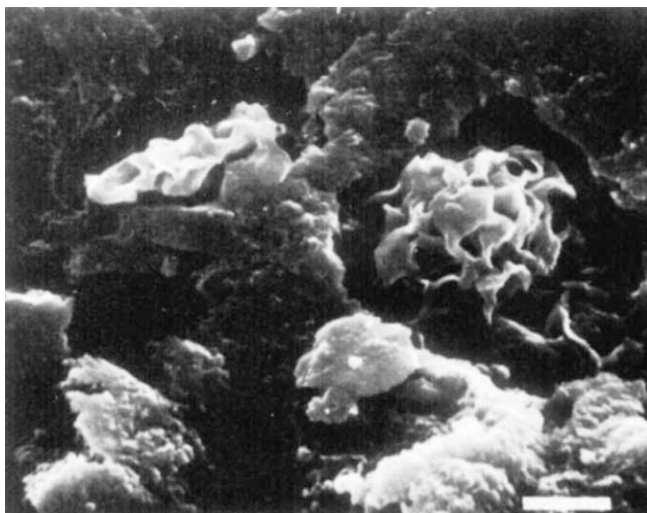


Fig. 2 SEM photomicrograph of porcellanite fracture surface and hydrous mica rosette. Scale bar, $2 \mu\text{m}$.

the diagenetic reaction of smectite to hydrous mica and the formation of chert. The habit and distribution of the hydrous mica in the porcellanite layer strongly suggest that it is authigenic, and its formation from a smectite would release large quantities of silica. A release of silica is strongly indicated by the different silicon-aluminium ratio in the smectite and the authigenic hydrous mica. Aluminium is assumed to remain conserved during the reaction.

The actual amount of silica released depends on the chemical composition of the smectite and hydrous mica. For example, it can be calculated that the stoichiometric transformation of 10 g of montmorillonite could produce 6.4 g of hydrous mica and 3.3 g of quartz. These proportions do not, however, have to be represented within the same sedimentary layer. Assuming that all the silica released is precipitated, the amount of pelagic brown clay that would have to alter in the core can be calculated. The brown clay has an approximate porosity of 60%, and smectite composes 60% by weight of the solid phases, and the porcellanite layer has approximately 40% by volume opal-CT (density 2.4 g cm^{-3}). If the smectite has the ideal montmorillonite composition and it all alters, a sediment layer 0.4 cm thick could produce the silica for a 0.1 cm porcellanite layer. The important problems of why the porcellanite layer formed where it did and the mechanism and kinetics of the reaction are still being studied. Seawater is the most probable source of potassium. Based on a 60% porosity and on a conservative diffusion rate of $10^{-7} \text{ cm}^2 \text{ s}^{-1}$,

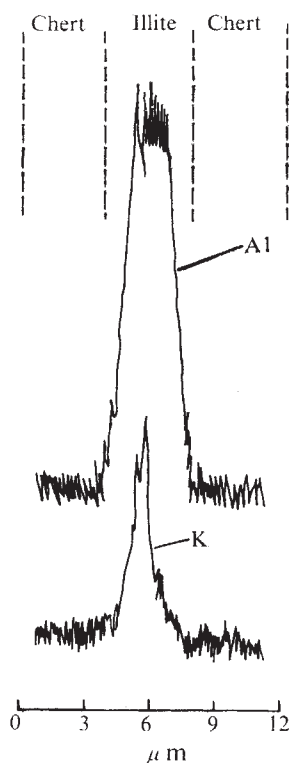


Fig. 3 Relative abundances of aluminium and potassium from an electron microprobe traverse across a fracture surface similar to Fig. 2.

all the potassium necessary to convert a montmorillonite layer of 0.4 cm into hydrous mica in the porcellanite layer, will be supplied in 20 yr. The high mobility of magnesium might account for the lack of a diagenetic phase rich in magnesium. Because of the low mobility of iron, the transformation of montmorillonite rich in iron to hydrous mica poor in iron should result in a higher concentration of iron oxide or hydroxide in the surrounding sediments. The

studied core was, however, rich in iron oxide throughout, making it difficult to prove such an enrichment.

The proposed mechanism of chert formation could be further supported by measuring the $^{18}\text{O}/^{16}\text{O}$ ratios of the coexisting hydrous mica and opal-CT. In addition, a separation of the hydrous mica could be dated to give the actual time of formation of the porcellanite, assuming argon is retained in the structure.

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BIOLOGICAL SCIENCES

Terminal deoxynucleotidyltransferase in murine plasmacytomas

FOUR different DNA polymerases have so far been described in animal cells. Two of them are present in all types of cells¹⁻⁵: the low molecular weight nuclear DNA polymerase, and the high molecular weight cytoplasmic DNA polymerase. The concentration of only the latter varies during the cell cycle, suggesting its involvement in DNA replication⁶. The two other DNA polymerases seem to exist only in certain cell types: the first, recently characterised⁷, seems to be directed by RNA, although differing from the oncornavirus reverse transcriptase⁸; the second is terminal deoxynucleotidyltransferase which does not exhibit the usual properties of DNA polymerases since it catalyses the polymerisation of deoxyribonucleotides in the absence of template by adding them randomly to the 3'OH end of oligo- or polydeoxyribonucleotides^{9,10}. This last enzyme is tissue-specific: it exists only on the thymus of the different species tested¹¹. Recently the terminal transferase was also identified in blood lymphoblasts of a child suffering from acute lymphoblastic leukaemia¹².

In addition to the DNA polymerase activities already described in murine plasmacytoma cells¹³, we have found in the course of our studies¹⁴ that these tumours also contain terminal deoxynucleotidyltransferase.

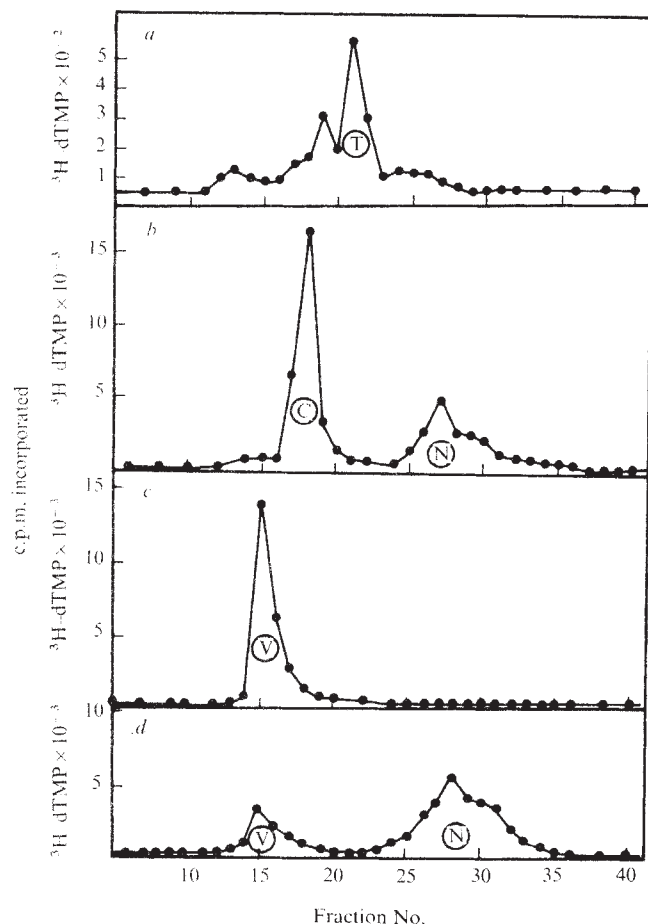


Fig. 1 Phosphocellulose chromatography of DNA polymerase activities from murine plasmocytoma MOPC 173 extracts. Subcutaneous tumours (2 g) were washed repeatedly in phosphate-buffered saline. After three cycles of freeze-thawing, they were homogenised by 10 strokes of a Teflon-glass motor-driven homogeniser in two volumes of TEM buffer (0.05 M Tris-HCl pH 7.9, 1 mM EDTA, 2.8 mM 2-mercaptoethanol). The homogenate was diluted in TEM buffer to 20 ml and Nonidet P40 was added (0.5% final). After slow mixing during 15 min at 0° C, the detergent-treated homogenate was centrifuged at 100,000g for 1 h. The pH of the supernatant was lowered to 5 by dropwise addition of 1 M acetic acid. The pH 5 precipitate was collected by centrifugation at 30,000g for 10 min, and redissolved in a minimal volume of TEMG buffer (TEM buffer containing 20% glycerol). The protein concentration of the pH 5 extract was adjusted to 2 mg ml⁻¹ and 10 ml were applied to a P11 phosphocellulose column (10 × 1.2 cm). After a 40 ml wash by TEMG buffer containing 500 µg ml bovine serum albumin (TEMG-BSA), the adsorbed proteins were eluted by an 80 ml gradient of 0–1 M KCl in TEMG-BSA, at a flow rate of 10 ml h⁻¹. Fractions of 2 ml were collected, and assayed for DNA polymerase activities. DNA polymerase assays were performed with 25 µl of each fraction in a final volume of 100 µl for 1 h at 37° C. Depending on the template primer used, the incubation mixture contained: *a*, d(pT)₄-primed reaction: 5 µmol of Tris-HCl (pH 7.4), 0.2 µmol of dithiothreitol, 0.08 µmol of Mn²⁺ (chloride), 0.3 A₂₆₀ unit of d(pT)₄ (Collaborative Research) and 250 pmol of ³H-dTTP (2,000 c.p.m. pmol⁻¹). *b*, Activated DNA-primed reaction: 5 µmol of Tris-HCl (pH 7.9), 0.2 µmol of dithiothreitol, 1 µmol of Mg²⁺ (chloride), 0.2 A₂₆₀ unit of activated calf thymus DNA²⁰ 5 nmol each of dATP, dGTP, dCTP and 200 pmol of ³H-dTTP (4,000 c.p.m. pmol⁻¹). *c*, rA_n·dT₁₀-primed reaction: 5 µmol of Tris-HCl (pH 7.9), 0.2 µmol dithiothreitol, 0.1 µmol Mn²⁺ (chloride), 0.02 A₂₆₀ unit of rA_n·dT₁₀ (Boehringer) and 1 nmol of ³H-dTTP (500 c.p.m. pmol⁻¹). *d*, rA_n·dT_n-primed reaction: as *c*, with 0.025 unit of rA_n·dT_n (Miles) in place of rA_n·dT₁₀. The acid-precipitable material was collected by filtration on Millipore filters and the radioactivity was counted in a Nuclear Chicago scintillation spectrometer. Each panel represents the results of the assays of the fractions of the same column, using one of the above template primers.

We used three different murine plasmocytomas: MOPC 173 and its two cell lines MF₂ and ME₂¹⁵, TEPC 15¹⁶ and MOPC 315¹⁷; as control cells we used normal BALB/c mouse thymic spleens from BALB/c nude mice, and L cells. The enzyme was detected using a method similar to that of McCaffrey *et al.*¹²: the cell homogenate was treated by a nonionic detergent, centrifuged at 100,000g and the pH of the supernatant was lowered to 5. The precipitate was solubilised and fractionated by chromatography on a phosphocellulose column. The elution profile from MOPC 173 is presented in Fig. 1 and from TEPC 15 in Fig. 2; MOPC 315 gave similar results. These profiles were obtained by assaying the protein fractions eluted from the column in conditions which discriminate between the different DNA polymerases by their ability to use specific template primers (Table 1). Plasmocytoma cells produce viral particles (type A and type C), and contain reverse transcriptase.

Table 1 Primer specificity of DNA polymerases from MOPC 173 tumours

Template-primers	DNA polymerases	MOPC 173 tumour enzymes*			C-type particles
		V (0.28 M)	C (0.35 M)	N (0.55 M)	
rA _n :dT _n (³ H-dTTP)		5.75	1.6	6.7	52
rA _n :dT _n (³ H-dATP)		0.06	0.70	0.02	0.00
rA _n :dT ₁₀ (³ H-dTTP)		12.2	0.47	0.00	65
dA _n :dT ₁₀ (³ H-dTTP)		0.02	1.42	7.20	0.00
rC _n :dG ₁₀ (³ H-dGTP)		4.60	0.45	0.00	50

*Molarity of elution from phosphocellulose

The assays were performed under the conditions described as in Fig. 1, with 20 µl of each phosphocellulose fraction. Incubations were at 37° C for 30 min. Type C particles were purified from the supernatant of MOPC 173 cells in culture by sucrose gradients as described¹⁴; they were tested with 50 µg of virus proteins per assay. The 0.55 M phosphocellulose enzyme can use rA_n·dT₁₀ as template if the temperature is lowered to 30° C, but even under these conditions it cannot use rC_n·dG₁₀.

For all the cells tested, the polymerases, when present, were eluted from the column as follows: viral reverse transcriptase (0.28–0.3 M KCl: 'V' enzyme) high molecular weight C polymerase (0.35 M), terminal deoxynucleotidyltransferase (0.4 M: 'T' enzyme) and low molecular weight N polymerase (0.55 M). The chromatogram shows some overlapping mostly between the first two enzymes. The separation between the C enzyme and terminal transferase is not always as satisfactory as in Fig. 1. Good resolutions were obtained when the 0.45 M KCl eluate from the phosphocellulose column (after a 0.25 M wash), was filtered on Sephadex G-150, the elution volume of terminal transferase being consistent with a molecular weight of about 30,000.

The thymus cells gave the same elution profile for terminal transferase as did the MOPC 173 cells. The complete results

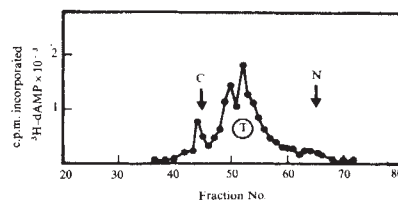


Fig. 2 Terminal deoxynucleotidyltransferase in TEPC 15 plasmocytoma tumours. The experimental procedure was the same as for MOPC 173 tumours (Fig. 1), with the exception of the fraction volumes (1 ml) and of the assay of the terminal transferase which was performed with d(pT)₁₀ (Boehringer) and ³H-dATP (250 pmol 2,000 c.p.m. pmol⁻¹). The arrows represent the fractions containing the other DNA polymerases (detected as in Fig. 1).

Table 2 DNA polymerases present in murine tissues

Polymerases	Reverse transcrip- tase V	High molecular weight poly- merase C	Terminal- transferase T	Low molecular weight poly- merase N
Tissue				
L cells	+	+	—	+
Athymic mouse spleen	—	+	—	+
Thymus	—	+	+	+
MOPC 173 (tumours)	+	+	+	+
MOPC 173 (cells in culture)	+	+	+	+
TEPC 15 (tumours)	+	+	+	+

Results were obtained by the method described in Fig. 1. Relative levels of activity are not shown.

summarised in Table 2 show that the terminal transferase is present only in thymus and plasmacytoma cells.

The properties of the terminal transferase extracted from plasmacytoma MOPC 173 are the same as those of the thymic enzyme: it uses different oligonucleotides as initiators (d(pT)₄, d(pT)₁₀, d(pG)₄ and d(pA)₁₀ were tested) and it polymerises separately each of the four deoxynucleoside triphosphates, with a better yield for dATP. A low self initiation takes place in the absence of initiator. Divalent cations are indispensable.

Since plasmacytoma cells are generally considered to be B cells¹⁸, the presence of terminal transferase in these tumours was unexpected. McCaffrey *et al.*¹² pointed out that the presence of this enzyme in leukaemic lymphoblasts would denote a thymic origin. But, neither in the McCaffrey's description nor in our study, have thymus antigens been checked. In most plasmacytomas, θ antigen is lacking¹⁸, whereas B antigen is present (E. Stockert, personal communication). Thus, it would seem plausible to assume that plasmacytoma cells represent an intermediate stage of differentiation between B and T cells, as has been previously proposed for a thymoma cell line¹⁹. Another hypothesis is that transformation by itself would have led to the derepression of terminal transferase. Further studies are needed before discussing these hypotheses in detail; work is in progress to check the complete set of antigens expressed on plasmacytoma cells; it would also be of interest to isolate the thymic cell population responsible for the terminal deoxynucleotidyltransferase activity.

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Interaction between the antibiotic tyrocidine and DNA *in vitro*

VERY little is known about the natural function of the peptide antibiotics. The production of antibiotics may be related to sporulation as only sporulating microorganisms produce antibiotics¹. In general, the synthesis of antibiotics occurs within a limited time at the end of the logarithmic growth of cell cultures², concurrent with a change in the specificity of transcription³. Loss, through mutation, of the ability to synthesise the antibiotic leads to asporogeny, in some cases⁴. Specific inhibitors and changes in culture conditions affect both the synthesis of antibiotic and sporulation⁴. Sarkar and Paulus⁵ demonstrated that the cyclic peptide antibiotic, tyrocidine, produced by *Bacillus brevis* (ATCC 8185) effects RNA synthesis *in vivo*, whereas DNA synthesis continues. Moreover, these authors give evidence that tyrocidine inhibited an *in vitro* RNA transcriptional system using *B. brevis* DNA and *B. brevis* DNA-dependent RNA polymerase. Complete inhibition of RNA synthesis with a tyrocidine concentration comparable to that in a *B. brevis* cell at the end of the vegetative growing phase was observed. A strong binding of the oligopeptide antibiotics, neotropin and distamycin A, to double-stranded DNA, resulting in a pronounced heat stabilisation of the double-strands, has been reported⁶. Compared with pure DNA, these peptide-DNA complexes exhibit a low template activity⁷.

In this report we describe experiments demonstrating that tyrocidine interacts *in vitro* with DNA. A complex formation between the initiation sites and tyrocidine is suggested as the mode of action.

RNA polymerase was isolated from a logarithmic growing cell culture of *B. brevis* (ATCC 8185) according to the method of Burgess⁸ except that the polymerase was eluted from DEAE cellulose by a linear KCl gradient instead of stepwise. The enzyme, finally purified on a linear glycerol gradient, was tested for purity by polyacrylamide gel electrophoresis. The enzyme was at least 90% pure. SDS gel electrophoresis revealed three main components with molecular weights of about 45,000, 55,000 and 160,000, corresponding to the 2 α s, σ and β/β components of the polymerase respectively⁹. In addition there was an unknown component with a molecular weight of about 120,000 which has been already described by Sarkar and Paulus⁹. In contrast to the report of these authors, σ was not released during glycerol gradient centrifugation. This polymerase transcribed both *B. brevis* DNA and calf thymus DNA. In both cases transcription was inhibited proportionally by added tyrocidine. Complete inhibition was achieved when 20 μ g tyrocidine was added to a 250 μ l transcription assay containing 7 μ g *B. brevis* DNA, or when 25 μ g tyrocidine was added to the same system containing 2 μ g calf thymus DNA. The tyrocidine concentration was thus similar to that which Sarkar and Paulus⁹ found to be inhibitory in their transcription assay

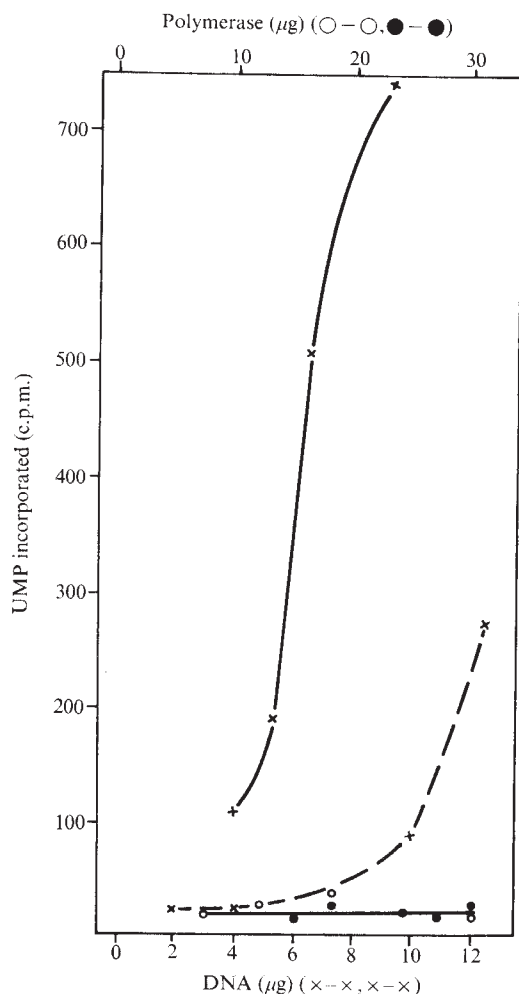


Fig. 1 Effects of DNA and of RNA polymerase on transcriptional system inhibited by tyrocidine. Transcription of 7 μ g *B. brevis* DNA was inhibited by tyrocidine to 87%. To this system increasing amounts of *B. brevis* DNA were added ($\times$ — $\times$). In parallel transcription was inhibited to 100% and increasing amounts of RNA polymerase were added ($\bullet$ — $\bullet$). Transcription of 2 μ g calf thymus DNA was inhibited by tyrocidine to 100%. To this system increasing amounts of calf thymus DNA ($\times$ — $\times$) or RNA polymerase ($\circ$ — $\circ$) were added. Polymerase was isolated from cells grown in a rich medium (5 g peptone, 1.5 g yeast extract, 1.5 g beef extract, 3.5 g NaCl, 3.7 g K_2HPO_4 , 1.3 g KH_2PO_4 , 1.0 glucose in 1,000 ml of water) and collected during exponential growth. Polymerase was purified according to Burgess⁸ including the glycerol gradient step. The enzyme contained the σ subunit and was completely dependent on DNA. An incorporation of 16.3 pmol of UMP into RNA in the presence of 3.5 μ g *B. brevis* DNA was catalysed by 1 μ g of RNA polymerase within 30 min. *B. brevis* DNA was purified by treating cells with lysozyme (10 μ g ml⁻¹) for 5 min at 37° C followed by SDS treatment (0.2% sodium dodecyl sulphate in 0.1 M EDTA, 0.4 M NaCl, pH 7.8) at room temperature for 15 min. Protein was removed by phenol extraction. RNA was digested by RNase treatment (50 μ g ml⁻¹) for 90 min followed by pronase treatment (100 μ g ml⁻¹) for 180 min. Pronase was removed by phenol extraction. The DNA was finally purified by CsCl density centrifugation. Calf thymus DNA (Serva) was used without further purification. Transcription assays were carried out at 37° C for 30 min in the presence of 0.03 M Tris-HCl, pH 7.9, 0.15 M KCl, 0.005 M $MgCl_2$, 0.1 mM EDTA, 0.001 M 2-mercaptoethanol, 0.02 M each of ATP, GTP and CTP and 0.5 μ Ci ³H-UTP (52 Ci mmol⁻¹). For each assay (250 μ l) 6 μ g polymerase and 7 μ g *B. brevis* DNA or 2 μ g calf thymus DNA were used. Tyrocidine (Serva) was dissolved in methanol (2 mg ml⁻¹) and added to the assays. Transcription was terminated by adding cold trichloroacetic acid to a final concentration of 7%. The precipitates were collected on glass fibre filters (Whatman GF/C), washed with trichloroacetic acid and ethanol, dried and counted in a Nuclear Chicago liquid scintillation counter.

and was comparable to that in a *B. brevis* cell during the late logarithmic phase. The solvent used for tyrocidine, methanol, had a slightly stimulatory effect on RNA synthesis. Therefore the inhibition was not due to the solvent. When *B. brevis* polymerase was replaced by *Escherichia coli* RNA polymerase a comparable inhibition was obtained. Thus tyrocidine does not act only on the homologous DNA or on the homologous polymerase.

When increasing amounts of DNA were added to an inhibited transcription system, transcription could be restarted. In contrast, RNA polymerase did not affect an inhibited transcription system. This was the case for *B. brevis* DNA as well as for calf thymus DNA (Fig. 1). It is therefore likely that tyrocidine acts on DNA which is no longer accessible to the polymerase and that the polymerase is not affected by tyrocidine.

In the experiments described above, DNA was first mixed with tyrocidine, and the reaction started by the addition of polymerase. In other experiments transcription was allowed to proceed for some time before the addition of tyrocidine. In this case significant transcription ensued for a certain time after the addition of tyrocidine and was only later slowed down or stopped. A possible interpretation of this phenomenon, which was true for the *B. brevis* as well as for the calf thymus system, could be as follows: once transcription has started the transcribing polymerase cannot be stopped by tyrocidine. After terminating, however, no new initiation can occur because the initiation sites are blocked by the antibiotic. Following this interpretation, the target of tyrocidine would be the initiation of the transcription process.

To prove the hypothesis that tyrocidine interacts with DNA, complex formation has to be demonstrated. Sephadex G-25 gel filtration could not be used because tyrocidine adsorbs to the gel due to its high tryptophan content. A DNA-tyrocidine complex was detected by glycerol gradient

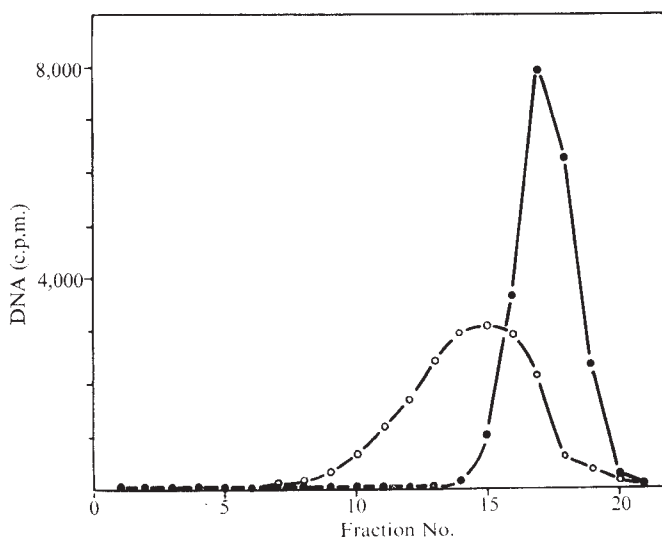


Fig. 2 Complex formation between *B. brevis* ³H-DNA and tyrocidine ($\circ$ — $\circ$) assayed by glycerol gradient centrifugation. ³H-DNA was isolated from *B. brevis* cultures which have been incubated with 1 μ Ci ³H-adenine (specific activity 21 Ci mmol⁻¹) per ml for several generations. Cells were broken and DNA purified as described in Fig. 1 except that the CsCl-purification step was omitted. The specific radioactivity of the DNA was 3,100 c.p.m. μ g⁻¹. A mixture of 20 μ g ³H-DNA and 20 μ g tyrocidine in 0.01 M Tris-HCl pH 7.8, 0.005 M $MgCl_2$, 0.01 M KCl was incubated for 10 min at 25° C. The complex was then layered on to a 14 ml 10–30% (v/v) glycerol gradient in buffer as above and centrifuged in a SW 27.1 rotor (Beckman, Spinco Ultracentrifuge) at 25° C for 12 h at 26,000 r.p.m. At the end of the run the gradient was fractionated, the DNA precipitated by trichloroacetic acid, and the radioactivity estimated. DNA without tyrocidine ($\bullet$ — $\bullet$) was run on a parallel gradient as a marker.

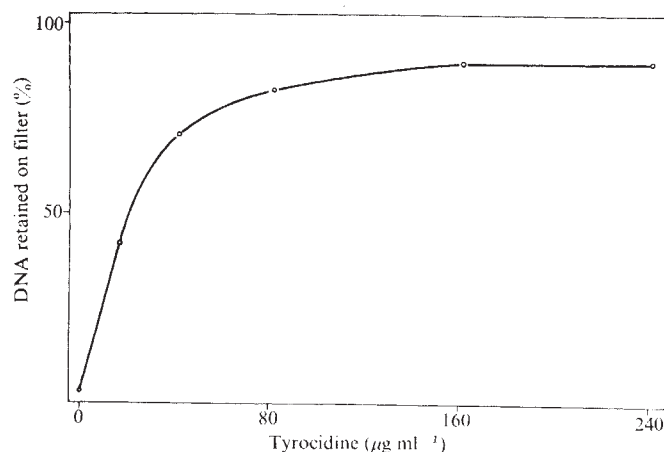


Fig. 3 Complex formation between *B. brevis* DNA and tyrocidine, assayed by the filter binding technique of Riggs *et al.*¹⁰. ³H-DNA was isolated from *B. brevis* cultures which had been incubated with 1 μCi ³H-adenine (specific activity 21 Ci mmol⁻¹) for several generations. In total volumes of 250 μl, 1.98 μg ³H-DNA were incubated with increasing amounts of tyrocidine for 10 min at room temperature in a buffer containing 0.01 M Tris, pH 7.8, 0.01 M magnesium acetate, 0.01 M KCl, 0.0001 M EDTA, 5% dimethylsulphoxide and 50 μg bovine serum albumin ml⁻¹. The mixture was then filtered slowly through a nitrocellulose filter (MF 100, Schleicher and Schüll) and was washed once with 0.8 ml of the same buffer but without albumin. The filter was dried and counted in a liquid scintillation counter. Under the conditions described, only 2–4% of the DNA was held back on the filter in the absence of tyrocidine.

centrifugation. ³H-labelled *B. brevis* DNA was incubated with tyrocidine at a concentration of 80 μg ml⁻¹ and centrifuged through a glycerol gradient. The majority of the DNA incubated with tyrocidine sedimented more rapidly than the marker DNA (Fig. 2), demonstrating complex formation. At a concentration of 160 μg tyrocidine ml⁻¹, most of the DNA was found to be on the bottom, whereas at a concentration of 40 μg tyrocidine ml⁻¹, most of the DNA moved in the position of the marker DNA.

Another way to demonstrate DNA-tyrocidine complex formation is the nitrocellulose filtration method of Riggs and Bourgeois¹⁰. In this system double stranded DNA does not adsorb to the nitrocellulose filter. When a complex is formed between DNA and a peptide or protein, the DNA complex is retained on the filter. In these experiments ³H-labelled *B. brevis* DNA was used. The amount of retained ³H-DNA is a measure of the complex formed. Without tyrocidine only about 2–4% of the DNA was bound by the nitrocellulose filter. Figure 3 illustrates the complex formation at a constant ³H-DNA concentration with increasing amounts of tyrocidine.

We tested the stability of the complex. To a complex of labelled DNA and tyrocidine, a 50-fold excess of cold *B. brevis* DNA was added and incubated for 1 h. At various times samples were withdrawn and filtered through nitrocellulose filters. It was found that 50% of the complex was broken down within 5 min, whereas the rest of the complex was almost completely stable for 1 h. It might be that about 50% of the initial complex detected on filters was a non-specific complex and was easily broken down. The remaining 50% stable complex might indicate a specific complex formation.

We conclude from our experiments that there is a complex formation between DNA and the antibiotic tyrocidine *in vitro*. Taking into account the observations from other laboratories, our results suggest that tyrocidine acts *in vivo* at the level of transcription by inhibiting the formation of polymerase-DNA complexes. This might reflect a control mechanism during the transition from the vegetative to the

sporulating cell, when many of the genes active during vegetative growth are switched off. Yoshida *et al.*¹¹ came to similar conclusions working with a different system. They found that vegetative cell cultures of *Streptomyces antibioticus*, which produces actinomycin D, are sensitive to actinomycin D. But the cells are insensitive to the compound during the transition of vegetative growth to sporulation. It is not yet known how genes are transcribed in late logarithmic or stationary cells which contain a high concentration of tyrocidine or actinomycin D. Experiments investigating the behaviour of RNA polymerase from sporulating cells in the presence of tyrocidine are in progress.

The final evidence for a regulatory role of the peptide antibiotic has to come from DNA-tyrocidine complexes isolated from cells and exhibiting a qualitatively different template activity compared with the template from vegetative cells.

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Activation of a C-type virus from the human carcinoma cell line HBT-3 by iododeoxyuridine and testosterone

We report the activation of a C-type virus from the human carcinoma cell line, HBT-3, with iododeoxyuridine following a testosterone-induced cellular morphology change. We feel that this method will prove useful in activating endogenous C-type virus. Studies are in progress to further characterise the virus and determine the species of origin.

The human breast tumour cell line, HBT-3, has been described in some detail¹. These cells have been maintained continuously as non-contact-inhibited epithelial cells (HBT-3Ep, Fig. 1a). The cells have a high cloning efficiency and an abnormal karyotype with three marker chromosomes. A DNA polymerase resembling the polymerase of RNA tumour viruses has been detected in this cell line². No virus particles have been detected however by electron microscopy (EM) or in tissue culture supernatants banded on sucrose gradients (personal communication from R. Bassin).

The induction of mammary carcinomas in the mouse results from an interaction between the murine mammary tumour virus

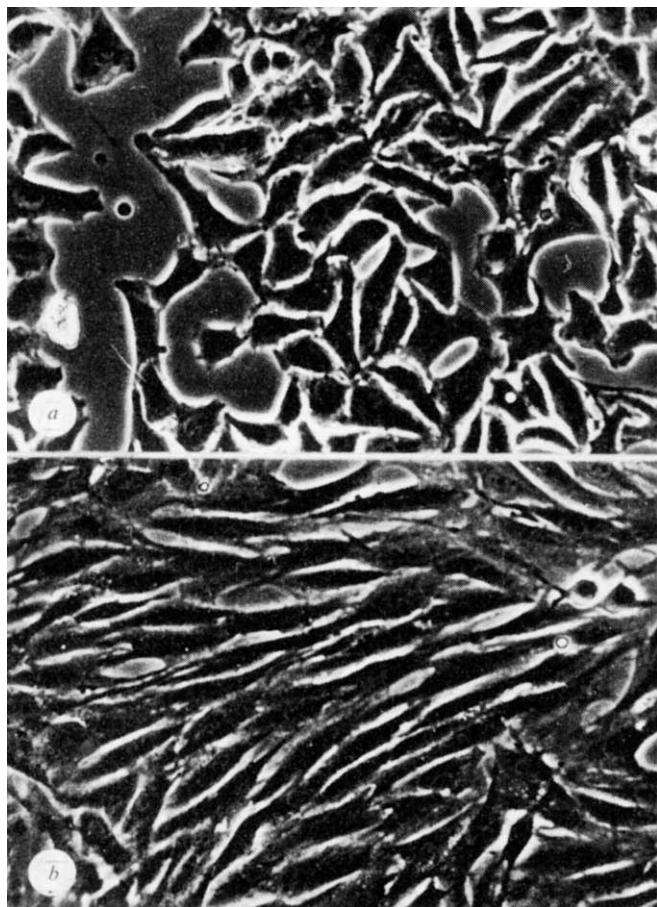


Fig. 1 Phase contrast microscopy of HBT-3 cells in cell culture. *a*, HBT-3Ep cells ($\times 286$); *b*, HBT-3 cells after prolonged cultivation with medium containing $5 \mu\text{g ml}^{-1}$ testosterone acetate ($\times 286$). Both cell types were grown at 37°C in 75 cm^2 plastic flasks (Falcon) utilising RPMI-1640 medium containing 15% v/v heat-inactivated foetal calf serum (Gibco), penicillin ($100 \mu\text{g ml}^{-1}$) and streptomycin ($10 \mu\text{g ml}^{-1}$). Weekly cell passages were made using 0.25% trypsin.

(MuMTV), the genetic susceptibility of the host and the hormonal environment³⁻⁷. Although murine mammary carcinoma has been studied extensively, other mammalian systems are less well characterised. Viruses with C-type morphology have been detected by EM in mammary carcinomas of the rat⁸, cat⁹ and rhesus monkey¹⁰. EM examination of human breast cancer biopsies has on occasion revealed virus-like particles¹¹⁻¹⁴, but virus has not been detected in human breast cancer cell lines^{1,15-16}. The RNA-dependent DNA polymerase (RDP) assay or the more rigorous 'simultaneous detection' of 60S-70S RNA have been used to detect oncornavirus-like properties in some human milk samples¹⁷⁻¹⁹. Keydar *et al.* have found particulates with similar properties banding at a density of 1.17 g ml^{-1} in the supernatant fluids of human embryonic cells cocultivated with human breast cancer cells or treated with milk from breast cancer patients known to contain 60S-70S RNA and RDP activity²⁰. RNA tumour virus expression in cell culture has been activated or enhanced by growing cells in the presence of halogenated pyrimidines, particularly iododeoxyuridine (IUdR) and bromodeoxyuridine²¹⁻²³. McGrath⁴ has shown MuMTV release concurrent with hormone-induced cellular organisation in cultured BALB/cF₃H mammary tumour cells. Moreover, IUdR rescue of C-type virus from mouse fibroblasts is markedly stimulated by the presence of adrenal glucocorticosteroids²⁴. We now report that a C-type RNA virus can be activated by IUdR from HBT-3 cells following a testosterone induced morphological alteration.

HBT-3 cells were obtained from Dr Robert Bassin (NCI) at passage level 28. A single clone derived from this cell culture was used for all subsequent studies. Cells grown in the presence and absence of $5 \mu\text{g ml}^{-1}$ testosterone acetate (Sigma) were observed frequently with a phase contrast microscope. After 8 weeks of continuous cultivation with testosterone, contact-inhibited spindle-shaped cells (HBT-3S) began to appear (Fig. 1*b*). Within 4 d these cells comprised 90% of the population and on subsequent passage no epithelial cells could be discerned by light microscopy. Karyotyping of the spindle-shaped cells revealed two of the original chromosome markers (personal communication from C. S. Stulberg). The lack of any significant change in cell numbers or cell doubling time indicates that the HBT-3Ep cells were morphologically changed to HBT-3S cells. If testosterone is removed within 2 weeks after this change the HBT-3S cells revert to the HBT-3Ep form, taking 2-3 weeks for reversal to occur. The change is not reversible, however, if testosterone is removed later than 2 weeks after the HBT-3S cells appear. These cells have been maintained in culture for up

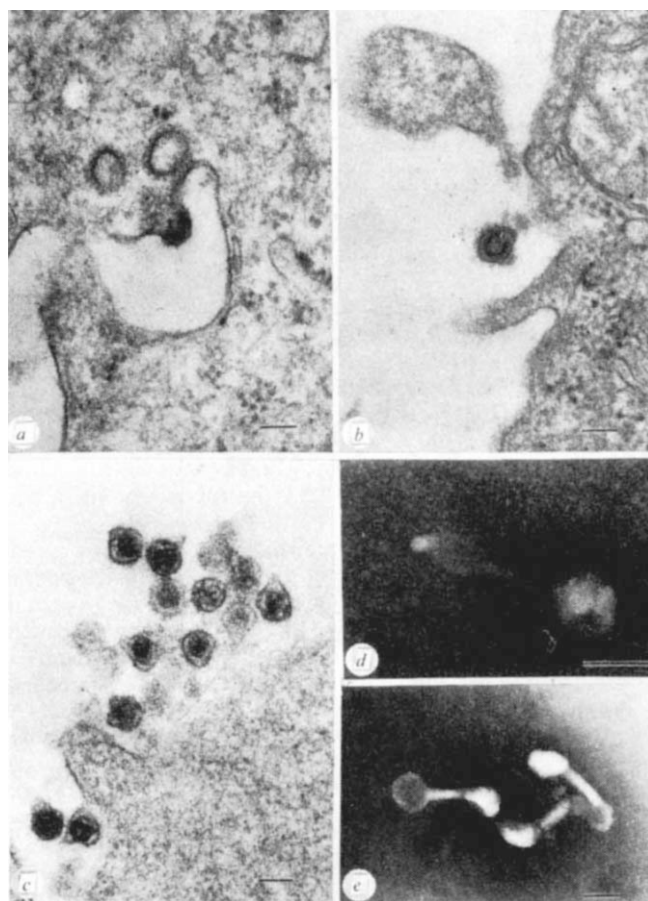


Fig. 2 Virus particles activated from HBT-3S with testosterone acetate and IUdR. *a*, C-type virus budding from cell membrane. The marker represents 100 nm. After IUdR-testosterone activation, cells were fixed in 2.5% glutaraldehyde, postfixed in 1% osmium tetroxide, dehydrated and embedded in Epon²⁶. Thin sections cut on an LKB Ultratome were stained with 2% aqueous uranyl acetate and lead citrate²⁷ and examined with a Phillips 300 electron microscope. *b* and *c*, Extracellular C-type virus. The marker represents 100 nm. *d*, Negatively stained preparation of virus using phosphotungstic acid (PTA). Virus containing fluid collected from IUdR-testosterone-activated cells was centrifuged at 4,000 r.p.m. for 15 min and the supernatant subjected to centrifugation at $95,000g$ for 60 min. The resultant pellet was suspended in 0.5 ml of 0.05 M sodium citrate and mixed 1:3 with 2% PTA and examined by EM on formvar-carbon coated grids. The marker represents 100 nm. *e*, Negatively stained virus from 1.15 g ml^{-1} band of isopycnic sucrose density gradient (see Fig. 3*b*). The marker represents 100 nm.

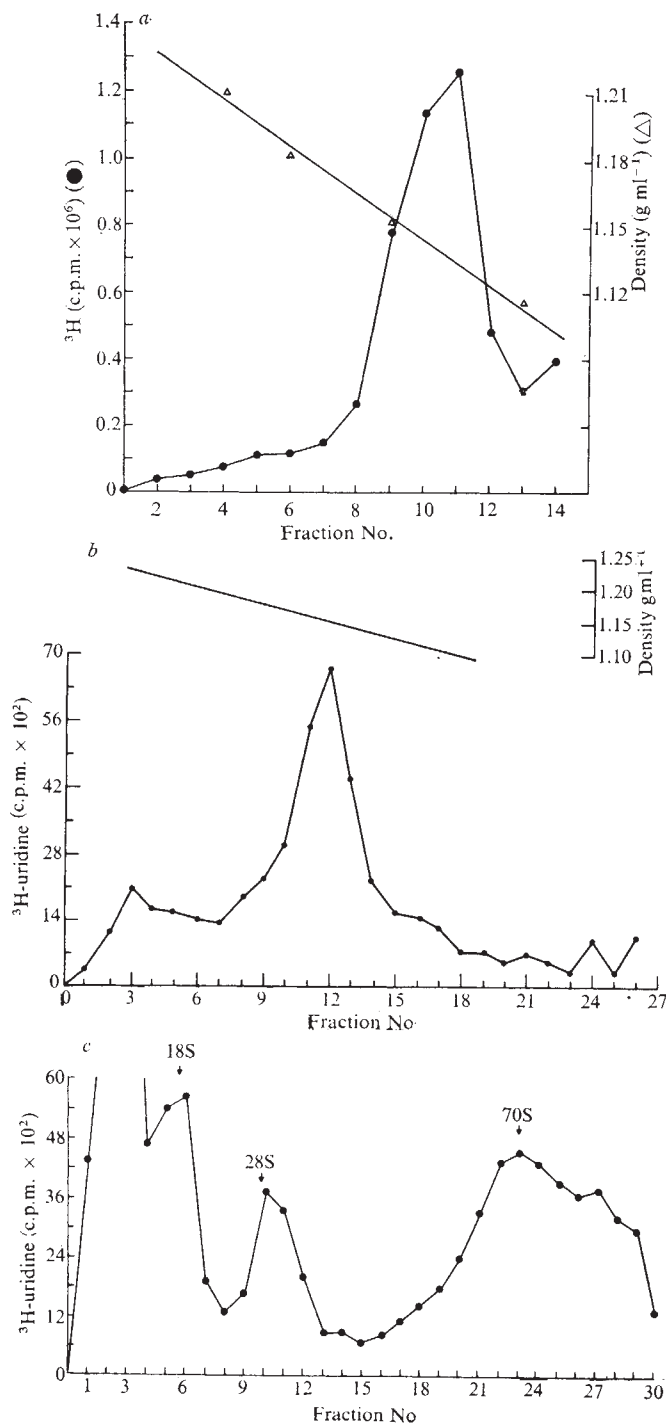


Fig. 3 RNA-dependent DNA polymerase activity and density of HBT-3S IuDR rescued virus and sedimentation rate of its associated RNA. *a*, RDP activity of virus banded in an isopycnic density gradient. IuDR-treated HBT-3S cultures were incubated for 72 h with $100 \mu\text{g ml}^{-1}$ IuDR. The collected culture fluids were clarified at $10,000g$ for 10 min. The clarified medium was then centrifuged at $80,000g$ for 60 min. The pellet from this centrifugation was resuspended in phosphate buffered saline, layered over a 10–65% linear sucrose gradient in a Beckman SW-40 rotor and centrifuged for 4 h at $200,000g$. Sedimentation is from right to left. The indicated fractions were diluted to 5 ml with cold growth medium and centrifuged at $80,000g$ for 60 min in a Beckman No. 30 rotor. The tube was drained, 120 μl of a detergent solution was added and two 50 μl aliquots were added immediately to 50 μl reaction mixtures, with (+) and without (–) added polyribadenylic-oligodeoxythymidylic acid (poly (rA):poly (dT)_(12–18)) template. The final reaction in 0.1 ml contained 0.016% Nonidet P-40 (Shell Chemical Co.), 30 mM *tris*-hydroxymethylaminomethane (Tris) hydrochloride (pH 8.5), 50 mM dithiothreitol (DTT), 0.5 mM manganese acetate, 30 mM sodium chloride, (+) 0.10 A_{260} units poly (rA):poly (dT)_(12–18), 1.0 μM thymidine triphosphate (TTP) methyl- ^3H (55 Ci

to 3 months. In repeated EM examination no virus was detected in either thin section of cells or in negatively stained preparations of cell-free supernatants in the HBT-3Ep or the HBT-3S cells. Moreover, no significant levels of RDP were detected in the cell-free supernatant of either cell type (Table 1). To determine whether virus expression in either cell type could be induced by IuDR, HBT-3Ep and HBT-3S cells were exposed for 3 d to medium containing IuDR (P-L Biochemicals) at a concentration of $100 \mu\text{g ml}^{-1}$ (ref. 25). After IuDR treatment only the HBT-3S cells produced C-type virus detectable by both RDP assay (Table 1) and EM (Fig. 2).

The virus is typically 85–100 nm in external diameter with a 40–58 nm core (Fig. 2). It is found extracellularly and budding from the cell membrane in a characteristic C-type formation (Fig. 2*a*, *b* and *c*). It does not resemble MuMTV³ which has A and B-type particles or the Mason–Pfizer monkey virus (MPMV)¹⁰ which buds as a B-type virus. Phosphotungstic acid (PTA) negatively stained preparations reveal tailed C-type particles without surface spikes with occasional blebs on the tails (Fig. 2*d* and *e*).

Table 1 RNA-dependent DNA polymerase activity of HBT-3Ep and HBT-3S cells treated with IuDR and testosterone

	HBT-3Ep	HBT-3S*
Control	96	152
IuDR†	120	18,190

RDP activity is expressed in c.p.m. For details of assay see legend to Fig. 3*a*.

*HBT-3S cells were derived from HBT-3Ep cells by testosterone as described in the text. Testosterone was maintained in the culture medium for 6 weeks after the appearance of the HBT-3S cells at which time they were used in this study.

†Iododeoxyuridine, $100 \mu\text{g ml}^{-1}$ of medium for 3 d.

RDP analysis of supernatants of the IuDR-induced HBT-3S cells banded in sucrose reveals a single peak of maximum activity at a density of 1.13 to 1.15 g ml^{-1} (Fig. 3*a*). When HBT-3S cells are isotopically labelled with ^3H -uridine during IuDR induction, a band of labelled virus is obtained at a density of 1.15 g ml^{-1} (Figs. 2*e* and 3*b*). RNA extracted from this band by the phenol method and sedimented on a sucrose gradient reveals both 70S and 28–30S ^3H -uridine labelled regions unique to C-type viruses (Fig. 3*c*). Thus, the biochemical and morphological characterisation identify this as a C-type virus.

mmol^{-1}) and was incubated for 30 min. at 37°C . Trichloroacetic acid (TCA) precipitable material was counted on membrane filters (Schleicher and Schuell) in a Packard model 3375 scintillation spectrometer. The data are corrected for (–) poly(rA):poly(dT)_(12–18) (< 200 c.p.m.). *b*, Isopycnic sucrose density gradient centrifugation of ^3H -uridine labelled virus from IuDR-activated HBT-3S cells. Conditions were as in (*a*) except that ^3H -uridine ($50 \mu\text{Ci ml}^{-1}$) was added simultaneously during IuDR induction and 25 μl aliquots were counted. Sedimentation is from right to left. *c*, Sucrose gradient sedimentation of RNA extracted from 1.15 g ml^{-1} ^3H -uridine labelled virus. Fractions between 1.136 and 1.165 g ml^{-1} (from *b*, above) were pooled and diluted to 25 ml with TNE buffer (0.01 M Tris, pH 7.5, 0.1M NaCl, and 0.001 M EDTA). The pool was centrifuged for 60 min at $80,000g$ and the virus pellet was resuspended in 200 μl of a solution containing 0.25M Tris, pH 7.5, 0.05M EDTA, 2.5% sodium lauroyl sarcosinate, 6% sodium dodecyl sulphate (SDS), 2.5 mM magnesium chloride and 0.1 mM calcium chloride. An equal volume of TNE buffer-saturated phenol was added. The suspension was vortexed and 2.5 volumes of ethanol (-20°C) were added to the aqueous phase. The precipitate was solubilised in 400 μl of TNE buffer (0.1% SDS) and sedimented through a linear sucrose gradient (10–30% w/v sucrose in TNE plus 0.1% SDS) for 3.5 h at $200,000g$ in a Beckman SW-40 rotor. Sedimentation is from left to right. Each fraction was combined with 100 μg yeast carrier RNA, precipitated onto TCA filters and counted as above.

Preliminary immunological evaluation of the virus by means of indirect immunofluorescence studies of the IUdR-treated cells reveals a lack of activity with antisera to rat (R-35), murine (Rauscher), feline (feline leukaemia and RD114) and primate (woolly monkey, MPMV, and gibbon ape) viruses. Repeated attempts to cultivate this virus in human and other mammalian cells have not been successful nor does this virus have an observable effect on HBT-3Ep or HBT-3S cells. Intraperitoneal and subcutaneous inoculations of BALB/c mice with 10^7 virus particles have not revealed pathological characteristics for up to 4 months after inoculation.

The requirement for testosterone as a prerequisite to viral activation suggests that it, together with IUdR, has a de-repressing function on the viral genetic information within HBT-3S cells. However, demonstration of antigenic determinants and nucleic acid homology to human cancer cells remain to be completed before any definitive statement regarding virus origin can be made. Moreover, the role of this virus, if any, in the aetiology of human cancer remains to be fully elucidated.

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Note added in proof: The presence of chromosomes in HBT-3 cells characteristic of HeLa has been reported²⁸. Although the origin of the HBT-3 cells is uncertain, we have established that testosterone and iododeoxyuridine may be used to activate a C-type virus from them and may be a useful technique for virus activation in other cell systems.

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Hepatitis B-specific DNA polymerase activity during post-transfusion hepatitis

HEPATITIS B antigen (HB_{Ag}, Australia antigen) has been associated definitively with long incubation human hepatitis¹⁻⁴. It appears before the onset of acute illness^{3,4} and decreases during convalescence, with the concomitant development of anti-HB_{Ag}⁵. In addition to this classical course of the disease, the discovery of HB_{Ag} has revealed sub-clinical infections, as demonstrated by seroconversion to HB_{Ag} (ref. 6), and the carrier state, where antigen is present in blood for long periods with either chronic hepatitis or no apparent disease⁷. Levels of HB_{Ag} in blood seem unrelated to the severity of disease, for carriers who generally have high titres of circulating antigen, in most cases, show slight if any liver damage^{8,9}.

Several structures found in plasma carry HB_{Ag} determinants¹⁰⁻¹⁴ including 43 nm spherical particles with 27 nm electron dense cores first described by Dane *et al.*¹⁴. DNA polymerase activity is associated with the core of a sub-population of Dane particles in apparently normal carriers¹⁵. We have now found polymerase-containing particles in blood during acute infection.

We collected serial plasma samples from multiply transfused patients at frequent intervals after surgery, and analysed them for HB_{Ag} by a solid phase radioimmunoassay¹⁶, for anti-HB_{Ag} by passive haemagglutination¹⁷ and for serum glutamic-pyruvic transaminase (SGPT)¹⁸. Some samples had been stored at -20°C for up to 3 yr.

Undiluted plasma (25 μl) was used to detect DNA polymerase activity by the procedures described before¹⁵. When polymerase activity was detected, we investigated whether it was HB_{Ag}-specific. Test samples (50 μl) were mixed with 15 μl of either guinea pig anti-HB_{Ag} (ay) (NIAID Research Resource Reagent V802-501-558) or normal guinea pig serum, and incubated at 37°C for 60 min. Rabbit anti-guinea pig IgG (50 μl) was then added and followed by incubation at 37°C for a further 60 min. The preparation was then centrifuged at 1,300g for 15 min and 50 μl of supernatant was removed and assayed for polymerase activity. Polymerase was considered to be specific if anti-serum directed against HB_{Ag} removed activity from the supernatant while normal serum had no effect.

In the first experiment coded specimens from three patients were tested for the presence of DNA polymerase activity. In a patient who received nineteen 500 ml units of whole blood during open-heart surgery (one of which was positive for HB_{Ag} by radioimmunoassay but negative by counterimmuno-

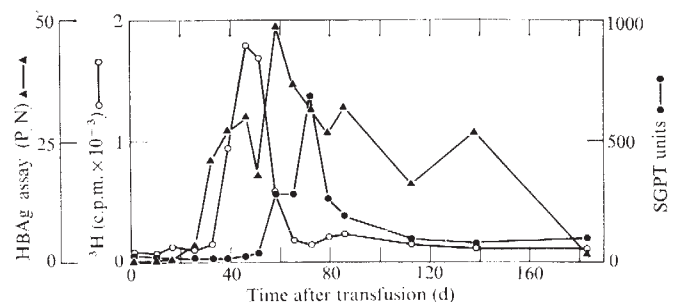


Fig. 1 A case of post-transfusion HB_{Ag}-positive hepatitis. Serial plasma samples were tested for HB_{Ag}-specific DNA polymerase. (O); HB_{Ag} by radioimmunoassay (▲); and SGPT levels (●).

noelectrophoresis) and who subsequently developed post-transfusion type B hepatitis, the first sign of infection was detection of HBAg at day 25 (Fig. 1). Fourteen days later DNA polymerase activity could be detected in unconcentrated serum. Using ten-fold concentrates prepared as described before¹⁰, DNA polymerase could be detected 7 d after the appearance of HBAg (day 32). Polymerase activity reached a peak on day 46, after which it decreased rapidly. The level of HBAG-specific polymerase was low when the peak titre of HBAG was observed (day 58), and was no longer detectable when the peak SGPT was reached (day 72).

Figure 2A shows the pattern observed with a patient who received HBAG-negative blood units and appeared normal throughout the study. Serum transaminase levels in this patient were never increased and no HBAG was demonstrated by radioimmunoassay. DNA polymerase activity was not detected in serial samples obtained during the 6 months following transfusion. Figure 2B shows the pattern for a patient who developed post-transfusion HBAG-negative hepatitis. Transaminase levels were normal until day 37, when they increased, reaching a maximum of 1,200 on day 44. Throughout the disease no serial samples had detectable DNA polymerase activity.

Table 1 Presence of HBAG-specific polymerase in multiply transfused surgical patients

Group	SGPT*	HBAG†	No. positive‡/No. tested
1	+	+	7/9
2	+	0	0/1
3	0	0	0/4

* Increased to >100 U ml⁻¹.

† Greater than 2.1 times the mean of negative controls by a solid phase radioimmunoassay.

‡ Tested for specificity by immunoprecipitation.

Serial samples from a number of multiply transfused patients were tested under code for polymerase activity and the results obtained, as well as those for the three cases previously described, are summarised in Table 1. Seven of the nine patients who developed post-transfusion hepatitis B as indicated by the presence of HBAG and elevated SGPT (group 1) had detectable HBAG-specific DNA polymerase activity in their plasma during acute infection. In all cases this preceded signs of liver damage as measured by elevated SGPT levels, and appeared slightly after HBAG was first detected. Polymerase activity was not found in the plasma of a patient with HBAG-negative post-transfusion hepatitis (group 2, Fig. 2B) nor in four control individuals (group 3). No individual in groups 2 and 3 developed antibody against HBAG. One of the four controls showed polymerase activity, however this activity could not be precipitated with specific antibody and was therefore not considered positive. One of the two individuals with HBAG-positive post-transfusion hepatitis who was considered negative for DNA polymerase also showed this non-specific polymerase activity.

These results show that in most cases HBAG-specific DNA polymerase activity can be detected in plasma from acutely infected individuals. Peak levels of activity detected were higher than those found in the plasma of most carriers (unpublished results). The transient nature of enzyme-containing Dane particles in the blood, and the time at which the peak activity was found resembles the viraemias associated with other viral diseases^{19,20}. These data support the hypothesis that the Dane particle is the virus of hepatitis B.

Virus-induced liver damage was not responsible for the presence of the DNA polymerase activity for several reasons. First, activity appeared before liver damage; second, in post-transfusion HBAG-negative hepatitis, where levels of SGPT were increased (Fig 2B), no polymerase activity was detected; and third, the enzymatic activity was associated with an antigenic particle, for highly specific anti-HBAG

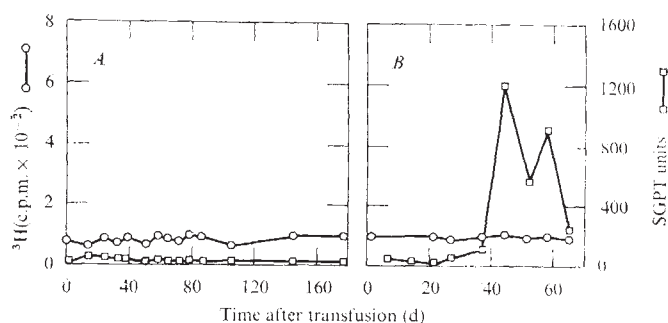


Fig. 2 Two multiply transfused surgical patients, one who showed no clinical disease and was HBAG-negative throughout the course of the study (A), and one who developed post-transfusion HBAG-negative hepatitis (B). Serial plasma samples were tested for DNA polymerase activity (O) and SGPT levels (□).

precipitated the activity.

Clearly, the radioimmunoassay detects HBAG before the demonstration of DNA polymerase activity, but it detects all antigenic structures in plasma while DNA polymerase activity is much more restricted and is probably only a measure of the presence of circulating Dane particles. If the Dane particle is the virus of hepatitis B, then the actual titre of infectious virus in an HBAG-positive serum may correlate better with the level of specific DNA polymerase than with the titre of HBAG.

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Detergent-solubilised H-2 alloantigen is associated with a small molecular weight polypeptide

THERE have been several reports that purified papain-solubilised HL-A alloantigens contains two polypeptides with molecular weights of approximately 31,000 and 11,500 (refs 1-3). The combined molecular weights of these two polypeptides (42,500) is similar to the molecular weight reported for detergent-solubilised HL-A alloantigens (43,000) (ref. 4). The smaller fragment seems to resemble β_2 microglobulin^{3,5}, which has an amino acid sequence homologous to that of an immunoglobulin heavy chain constant region domain⁶. This smaller fragment does not seem to contain any alloantigenic activity⁵ and is found in association with several different HL-A alloantigenic molecules^{1,3}. Further evidence of the close association of these two polypeptides is based on observations that capping or immunoprecipitation of β_2 microglobulin using antisera directed against β_2 microglobulin results in the cocapping⁷ or coprecipitation⁸ of HL-A molecules. One critical question is whether the HL-A alloantigens and β_2 microglobulin are covalently⁵ or noncovalently joined to one another. Our studies on a homologous system, the H-2 complex of the mouse, suggest that mouse H-2 alloantigens are noncovalently associated with a small polypeptide.

We report here that detergent-solubilised H-2 alloantigens from the mouse, purified by immunoprecipitation, contain two polypeptides with molecular weights of 47,000 and 11,500. Since the smaller polypeptide has a molecular weight comparable with that of the β_2 microglobulin molecule associated with HL-A alloantigens, it seems likely that it represents the murine equivalent of β_2 microglobulin. Also, since our solubilisation and purification procedure does not include any known proteolytic action, we propose that the small polypeptide does not represent a covalently-linked component of the H-2 alloantigen, but rather represents a molecule which for unknown reasons has a strong affinity for the major histocompatibility antigen of mice.

Proteins of B10.D2 spleen lymphocytes were labelled with either ¹²⁵I according to Marchalonis *et al.*⁹, or by culturing spleen lymphocytes in Hanks balanced salt solution (Gibco) in the presence of ³H-amino acids for 4-8 h. Briefly, radioiodination was performed by suspending 5×10^7 spleen lymphocytes in 0.5 ml of a phosphate buffered saline (PBS) solution at pH 7.4 which contained 100 μ g lactoperoxidase and 5 mCi ¹²⁵I. Hydrogen peroxide (50 μ l of 0.03% solution in PBS) was added and the suspension was incubated for 5 min at room temperature. This was followed by washing of the cells in PBS. Lactoperoxidase-catalysed radioiodination labels cell surface proteins only⁹ whereas the short culturing procedure using ³H-amino acids labels all proteins with a rapid turnover rate. Membranes of labelled cells were solubilised by incubation with 0.5% Triton X-100 (Sigma) in a mixture of 0.01 M Tris buffer, pH 7.4 and 0.15 M NaCl for 20 min at 0° C. Labelled immunoglobulin was preprecipitated by the addition of normal mouse serum and rabbit anti-mouse immunoglobulin. H-2 alloantigenic activity was immunoprecipitated as described in Fig. 1. Sodium dodecyl sulphate (SDS) acrylamide gel electro-

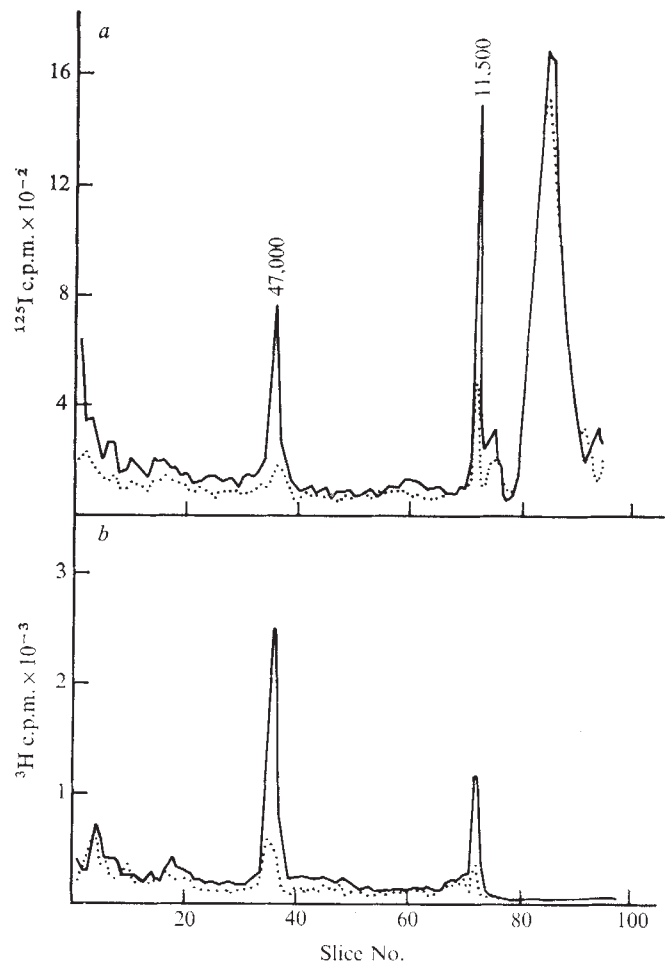


Fig. 1 Antigen preparations labelled with either ¹²⁵I (a) or ³H (b) from which labelled immunoglobulins had been removed by preprecipitation were treated with either 4 μ l of D-4 H-2 alloantiserum and 16 μ l of C57BL/10 normal mouse serum (—) or 20 μ l of C57BL/10 normal mouse serum (---). H-2 alloantiserum D-4, which was obtained from the National Institutes of Health, was made in the strain combination (B10. AKM $\times$ 129) F₁ anti-B10.A, and is therefore directed against the H-2.4 antigenic specificity of the H-2D region of the H-2^a haplotype. After incubation for 30 min at 0° C, 100 μ l of rabbit anti-mouse immunoglobulin was added and incubated at 0° C for 150 min. The resultant precipitate was washed three times, dissolved in 100 μ l of Laemmli reducing buffer¹⁰, and electrophoresed on 10% polyacrylamide SDS gels according to Laemmli¹⁰. Gels were cut into 1 mm thick slices and counted in either a gamma counter (¹²⁵I) or a liquid scintillation counter (³H). Molecular weights of the major peaks are indicated.

phoresis of the immunoprecipitate of H-2.4 alloantigenic activity in the presence of reducing agent revealed two polypeptide chains with molecular weights of 47,000 and 11,500 respectively, and a third peak of radioactivity which moved with the front, was dialysable, and was present in both the specific and nonspecific immunoprecipitates to the same extent (Fig. 1a). When a ³H-amino acid-labelled antigen preparation was used, immunoprecipitates yielded only two radioactive peaks coincident with the ¹²⁵I-polypeptides (Fig. 1b).

It should be noted that when normal mouse serum was used as a control in the immunoprecipitation method, small radioactive peaks were observed coincident with and in the same relative ratio as those observed using specific anti-H-2 serum. We believe that this is due to a small degree of reactivity of the small polypeptide (presumably the mouse analogue of β_2 microglobulin) with rabbit anti-mouse im-

munoglobulin, and that partial precipitation of this polypeptide by this reagent also results in partial coprecipitation of the H-2 alloantigenic molecule which is associated with it. SDS polyacrylamide gel electrophoresis of immunoprecipitates in the absence of reducing agent also revealed the smaller polypeptide peak, indicating that it was not bound by disulphide bonds to the larger polypeptide.

Our data indicate that the smaller polypeptide present in our immunoprecipitates is strongly associated with H-2 alloantigens, is present on the surface of lymphocytes, is rapidly synthesised, and has a molecular weight of 11,500. All of these properties are consistent with those of the β_2 microglobulin-like molecule associated with papain-solubilised HL-A alloantigens. Sequence analysis of the smaller polypeptide molecule is in progress in our laboratory to determine whether it is indeed the murine analogue of β_2 microglobulin. We feel that further speculation concerning the role of β_2 microglobulin as a component of HL-A alloantigens will require detailed chemical analyses of detergent-solubilised alloantigens.

Our investigations reveal that H-2 alloantigens are closely although noncovalently associated with a smaller polypeptide molecule. The strong affinity which these two membrane proteins exhibit for each other suggests that they may function as complementary receptors on the surfaces of lymphocytes and, accordingly, play a part in cellular recognition and/or interactions.

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Demonstration of acetylcholine-sensitive adenylyl cyclase in malignant neuroblastoma cells in culture

WE have recently reported¹ the existence of dopamine-sensitive adenylyl cyclase (AC) in mouse adrenergic neuroblastoma cells which contain tyrosine hydroxylase (TH) but no choline acetyltransferase (ChA); whereas, noradrenaline-sensitive AC at low noradrenaline concentrations becomes apparent in cyclic AMP induced 'differentiated' neuroblastoma cells. The presence of acetylcholine receptors in neuroblastoma cells has been demonstrated by Harris and Dennis². These acetylcholine receptors are blocked by nicotinic and muscarinic inhibitors³. We now report the presence of acetylcholine-sensitive AC in

addition to dopamine- and noradrenaline-sensitive AC in inactive neuroblastoma cells which contain neither TH nor ChA, and in cholinergic neuroblastoma cells which contain ChA but no TH. Acetylcholine, dopamine and noradrenaline produced an additive stimulatory effect on AC activity, suggesting that these neurotransmitters act on different receptor sites all of which are linked with AC.

The procedures for culturing and maintaining the mouse neuroblastoma cells were previously described⁴. Cells of previously defined⁵ clones NBDB⁻ and NBE^{-A} were used. The effects of dopamine, noradrenaline and acetylcholine on the AC activity in homogenates of malignant neuroblastoma cells were measured. Cells (0.5×10^6) were plated in large Falcon plastic flasks (75 cm²). The medium was changed first at day 2 and then every day thereafter. The samples for enzyme assay were prepared 4 d after plating. The cells were washed twice with phosphate buffer solution (pH 7.0), 5 ml of Tris-HCl (pH 7.5, 0.05 M) was added to each flask, and then the cells were removed from the flask surface using a Pasteur pipette. The contents of four flasks were pooled, and then the cells were frozen, thawed and homogenised. It is essential that cells are gently homogenised immediately after thawing as a longer interval between thawing and homogenisation decreases the enzyme activity. In addition, the stability of AC under frozen conditions varies from one clone to another. The stability of AC activity in frozen adrenergic cells could be maintained for more than a week; however, in cholinergic cells enzyme activity decreases by about 40% within a week. Therefore, the AC activity was assayed in samples which were frozen for a maximum of 3 d. The AC activity was determined by a modification⁶ of the procedure described by Krishna *et al.*⁷ Essentially, the formation of ³H-cyclic AMP from ³H-ATP is measured. The assay system was modified to include phosphoenolpyruvate and pyruvate kinase to recycle ADP formed by ATPase activity back to ATP. Also, cyclic AMP (0.8 mM) was included in the assay as a trap for the ³H-cyclic AMP formed during the incubation.

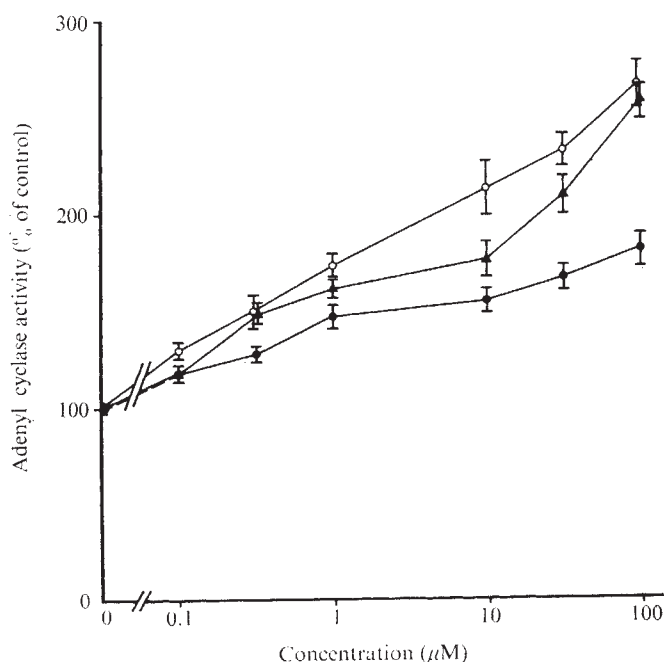


Fig. 1 Changes in adenylyl cyclase activity (AC) in homogenates of inactive neuroblastoma cells. The basal activity of AC (22 ± 2 pmol per mg protein per min) was considered 100% control values and the AC values of treated cells were expressed as percent of control. Each value represents an average of four to six samples. The bar at each point is standard deviation. Treatment with: ○, dopamine; ▲, acetylcholine; ●, noradrenaline.

tion. The incubation period for each sample was 15 min. The absorbance at 260 nm of the purified cyclic AMP fraction serves as a measure of recovery of ^3H -cyclic AMP. The formation ^3H -cyclic AMP was linear with time up to 30 min at 37°C and linear with protein concentration over the range $0.05\text{--}1.0\text{ mg ml}^{-1}$. The total volume of the incubation mixture was 1.0 ml. The protein was determined by the method of Lowry *et al.*⁸. Data were expressed as pmol cyclicAMP formed per mg protein per min.

The procedures for making solutions of dopamine, noradrenaline and prostaglandin ($\text{PG})\text{E}_1$ were previously described¹. To study the nature of receptors, propranolol (blocks β -receptors), phentolamine (blocks α -receptors), haloperidol (blocks dopamine-receptors), atropine (blocks acetylcholine-muscarinic receptors), hexamethonium and nicotine (blocks acetylcholine-nicotinic-receptors) were used. These agents were dissolved in 0.01 N HCl. Nicotine was dissolved in 70% ethyl alcohol. In addition, analogues of acetylcholine such as bethanechol and carbachol were used, since they are virtually resistant to acetylcholinesterase or non-specific cholinesterase. Carbachol stimulates both muscarinic and nicotinic receptors, whereas bethanechol has primarily nicotinic activity.

Figure 1 shows that low concentrations of acetylcholine, dopamine and noradrenaline stimulated AC activity in homogenates of inactive neuroblastoma cells. Noradrenaline was much less active than either dopamine or acetylcholine. A maximal stimulation of AC activity was achieved by $100\text{ }\mu\text{M}$ of any of these neurotransmitters; however, noradrenaline produced only 80% stimulation, whereas acetylcholine and dopamine produced about 160% stimulation in AC activity. None of the above neurotransmitters at a higher concentration ($1,000\text{ }\mu\text{M}$) produced any significant effect on the basal activity of AC.

Acetylcholine ($100\text{ }\mu\text{M}$) also stimulated AC activity in the cholinergic neuroblastoma cells to about the same extent as that produced in the inactive neuroblastoma cells (data not shown).

Table 1 shows that PGE_1 and serotonin also stimulated AC activity; however, adrenaline and histamine had no significant effect. Bethanechol and carbachol also stimulated AC activity, but less than did acetylcholine. The reasons for acetylcholine being more effective than bethanechol and carbachol are not known. When these agents were combined individually with acetylcholine, they produced an additive stimulatory effect on AC activity. The combination acetylcholine with dopamine or noradrenaline or both produced an additive stimulatory effect on AC activity, indicating that these agents act on the different receptors. Acetylcholine-stimulated AC activity was markedly reduced by atropine, nicotine, and hexamethonium;

Table 1 Effect of combination of various neurotransmitters on adenylyl cyclase activity in homogenates of neuroblastoma cells (NBDB⁻)

Treatment	Adenylyl cyclase activity (pmol per mg protein per min)
Control	$22 \pm 2^*$
Dopamine ($100\text{ }\mu\text{M}$)	58 ± 3
Noradrenaline ($100\text{ }\mu\text{M}$)	40 ± 1
Adrenaline ($100\text{ }\mu\text{M}$)	26 ± 2
Acetylcholine ($100\text{ }\mu\text{M}$)	57 ± 4
Bethanechol ($100\text{ }\mu\text{M}$)	36 ± 2
Carbachol ($100\text{ }\mu\text{M}$)	31 ± 2
Acetylcholine + bethanechol	88 ± 3
Acetylcholine + carbachol	77 ± 2
Dopamine + acetylcholine	100 ± 2
Noradrenaline + acetylcholine	92 ± 5
Dopamine + noradrenaline + acetylcholine	133 ± 3
Serotonin ($100\text{ }\mu\text{M}$)	24 ± 2
Histamine ($100\text{ }\mu\text{M}$)	24 ± 2
Prostaglandin E_1 ($10\text{ }\mu\text{M}$)	52 ± 3

*Standard deviation.

Change in adenylyl cyclase activity after treatment with various neurotransmitters in homogenates of inactive neuroblastoma cells. Each value represents an average of four to six samples.

but it was not significantly affected by haloperidol, phentolamine and propranolol (Fig. 2). Dopamine and noradrenaline stimulated AC activity was markedly inhibited by $10\text{ }\mu\text{M}$ of haloperidol and propranolol, respectively (data not shown). Atropine also reduced dopamine-stimulated AC activity; however, it reduced noradrenaline-stimulated AC activity only slightly (Fig. 3). Atropine, hexamethonium, nicotine, haloperidol, propranolol or phentolamine alone produced no significant effect on the basal activity of AC.

The reason for the marked reduction in dopamine-stimulated AC activity by atropine is unknown. Many blocking agents do not seem to be as specific as they have been presumed to be. For example, AC activity of neuroblastoma cells (unpublished observation) and of caudate nucleus⁹ is blocked by chloropramazine in a non-specific way. Haloperidol which is supposed to be specific inhibitor for dopamine-receptors also prevents noradrenaline-stimulated cyclic AMP level in rat brain slices¹⁰.

The fact that the muscarinic and nicotinic inhibitors of acetylcholine-receptors block acetylcholine-stimulated AC activity indicates that AC may be linked with both types of receptors. It has been suggested¹¹ that nicotinic receptors are linked with AC, whereas muscarinic receptors are linked with guanylyl cyclase. This concept does not appear to be applicable to this neuroblastoma clone.

Since dopamine and noradrenaline do not increase the cyclic AMP level until the phosphodiesterase activity is inhibited¹², these neurotransmitters may not mimic the effect of cyclic AMP in causing differentiation of neuroblastoma cells. Indeed, when the cells were exposed to dopamine and noradrenaline for 1 h, no differentiation occurred¹³, although dopamine induced reversible inhibition of cell division. A long drug-exposure was not feasible because these agents are auto-oxidised in solution. Acetylcholine ($100\text{ }\mu\text{M}$) did not produce any significant change on growth or differentiation (data not shown).

Our results demonstrate the presence of acetylcholine-sensitive AC in addition to dopamine- and noradrenaline-sensitive AC in inactive and cholinergic neuroblastoma cells. These cells thus differ from adrenergic cells in which acetylcholine-sensitive AC activity is not demonstrable and noradrenaline-sensitive AC activity does not become

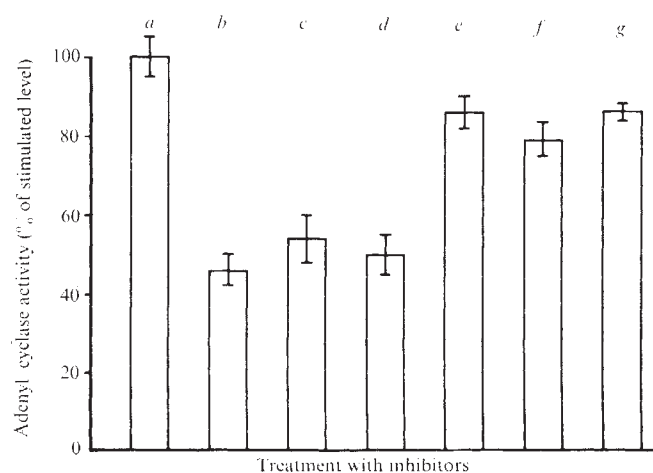


Fig. 2 Effect of various inhibitors of receptors on acetylcholine-stimulated adenylyl cyclase activity in homogenates of inactive neuroblastoma cells. A concentration of $30\text{ }\mu\text{M}$ of b, atropine; c, hexamethonium; d, nicotine; e, haloperidol; f, phentolamine or g, propranolol was added immediately before the addition of ACh ($100\text{ }\mu\text{M}$). a, The acetylcholine-stimulated activity of adenylyl cyclase ($57 \pm 4\text{ pmol per mg protein per min}$) was considered as 100%, and the values of AC in the presence of inhibitors were expressed as a percentage of the stimulated value. Each value represents an average of four to six samples. The bar at each point is standard deviation.

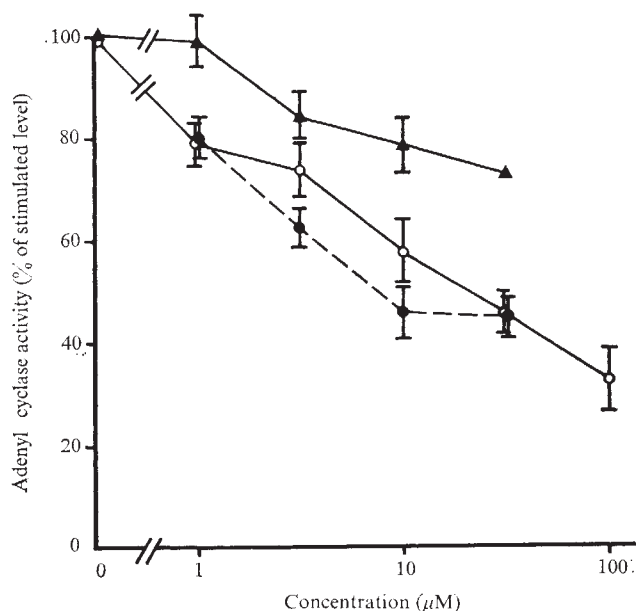


Fig. 3 Effect of atropine on acetylcholine (O), dopamine (●) and noradrenaline (▲)-stimulated activity of adenylyl cyclase (AC) in homogenates of inactive neuroblastoma cells. Atropine was added at various concentrations immediately before the addition of acetylcholine (100 μM), dopamine (100 μM) or noradrenaline (100 μM). The stimulated value of AC for dopamine (58 ± 3 pmol per mg protein per min), for acetylcholine (57 ± 4 pmol per mg protein per min) and for noradrenaline (40 ± 1 pmol per mg protein per min) was used as 100%, and the values of AC activities in atropine-treated homogenates were expressed as a percentage of the stimulated value. Each value represents an average of four to six samples. The bar at each point is standard deviation.

apparent until the cells are differentiated as a result of raised cyclic AMP levels^{4,12,14,15}. It is interesting that the application of dibutyl cyclic AMP or acetylcholine into the lateral hypothalamic area of rat greatly increased water intake¹⁶. Atropine completely inhibited food and water intake induced by dibutyl cyclic AMP¹⁶.

The fact that the adenylyl cyclase retains its sensitivity to low concentrations of acetylcholine and dopamine in homogenates of neuroblastoma cells suggests that this system may provide a sensitive method in search of new agents that can mimic or antagonise the effect of catecholamines and acetylcholine on mammalian neurones.

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Effect of cyclic AMP, caffeine and theophylline on differentiation of lens epithelial cells

PAPACONSTANTINO has clearly shown that differentiation of lens epithelial cells into fibre cells involves a complex series of morphological and biochemical events¹; however, at the molecular level the factors involved in the initiation of this differentiation are almost entirely unknown. The purification and characterisation of the mRNA species specifying bovine lens proteins² have made desirable the development of a system in which details of lens differentiation could be studied. Such a system for the study of lens epithelial cell differentiation in tissue culture should have the following characteristics: (1) The differentiation should demonstrate characteristic morphological changes which can be correlated with those expected of the process *in vivo*; (2) specific proteins characteristic of the differentiated tissue should be absent in epithelial cells inoculated into the culture and should appear during the course of the morphological changes; (3) it should be possible to maintain the epithelial cells in culture in an undifferentiated state by the criteria of unaltered morphology and the absence of specific proteins, and to induce them to differentiate in response to a specific set of conditions; (4) clones of epithelial cells should show characteristics similar to freshly explanted epithelial cells. In addition to these criteria, a useful characteristic of the system would be an accelerated or inhibited differentiation in response to hormones of cyclic nucleotides.

In establishing such a system, both the choice of protein to be monitored as an indication of differentiation and the tissue to be cultured may be critical. We observed in a previous study³ by immunofluorescent staining that epithelial cells at early stages of lens development in the rat do not contain γ -crystallins. In recent (unpublished) work we have found that when epithelial cells from embryonic or newborn rat lenses are cultured, no γ -crystallins can be found initially when fixed monolayer cultures of freshly explanted epithelial cells are stained by indirect immunofluorescence, but that subsequently such cells grow and differentiate morphologically, and in 5 d may be stained positively for γ -crystallins.

One of the most marked features of the monolayer cultures is the stimulation of cell growth and acceleration of the appearance of the γ -crystallins by dibutyl cyclic AMP. At 24 h, in contrast to controls (Fig. 1a), monolayers treated with dibutyl cyclic AMP (Fig. 1b) or caffeine (over the concentration range 10^{-6} to 10^{-3} M) exhibited patches of confluent growth and all the single cells were elongated in patterns similar to those observed for control cells only after three

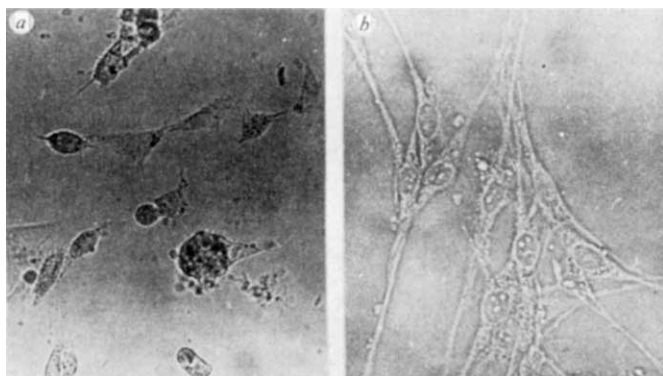


Fig. 1 Lens epithelial cells were removed from 1-d-old rat lens by 30 min treatment in medium 199 containing 0.08% trypsin at 37° C. A suspension culture of medium washed cells were incubated at 37° C in screw-capped shaker culture flasks. The cells were grown in suspension culture medium 199 containing 20% foetal calf serum, 0.1% D-L glutamine, penicillin G-sodium 100 U ml⁻¹ and dihydrostreptomycin sulphate 100 µg ml⁻¹. The pH was adjusted to 7.1 with sodium bicarbonate. After 5 d growth cells were inoculated in fresh medium into tissue culture chamber slides (Lab-Tek) at a density of 3.3×10^5 ml⁻¹. This high cell concentration was necessary since only 10–12% of the cells will attach to the glass. After 6 h the unattached cells were removed by sterile aspiration of the media and fresh media added. Monolayer cultures were incubated at 37° C, 100% humidity in an atmosphere of 5% CO₂-95% air. Medium (0.8 ml per chamber) was changed after 2 d and subsequently every 2 d. All test substances were present from the time of monolayer inoculation. Phase contrast micrographs were taken under white light 24 h after inoculation ($\times 370.50$). *a*, Normal cultures of lens epithelial cells; *b*, culture treated with dibutyl cyclic AMP (1×10^{-5} M).

days of growth. After 48 h in such treated monolayers strong γ -crystallin immunofluorescence was detected. No cell elongation or areas of confluent growth were found in monolayers incubated with butyric acid, cyclic GMP or theophylline (also over the concentration range 10^{-6} to 10^{-3} M), but caffeine potentiated the effect of cyclic AMP.

This effect is in marked contrast to the usual inhibitory effect of high concentrations of cyclic AMP on the growth of a number of cell lines⁴⁻⁸, and on the differentiation of an established myogenic cell line⁴. It occurs at much lower concentrations of cyclic nucleotide than used to stimulate differentiation of the mouse neuroblastoma cell line (5 mM) (ref. 9), or the temporary stellate configuration in adult newt iris cells¹⁰. It is likely that a growth response to cyclic nucleotides is typical of embryonic or neonatal cells¹¹, but the additional possibility of inducing differentiation in rat lens epithelial cells is expected to be valuable in exploring differentiation at the molecular level.

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New unstable haemoglobin (Hb Moscva, $\beta 24$ (B4) Gly $\rightarrow$ Asp) found in the USSR

THE unstable haemoglobins form a well-characterised group of human mutants which have been observed in many parts of the world¹. We have recently cooperated in the study of two such haemoglobins seen in Moscow. Haematological and clinical aspects have been published in Russia^{2,3}. One of the haemoglobins, discovered in a mildly anaemic patient who had pancreatitis (and in his son), was found to be Hb Tacoma ($\beta 30$ (B12) Arg $\rightarrow$ Ser), previously described in three members of a United States Caucasian family⁴. As this haemoglobin has already been fully characterised⁵ it will not be discussed further here.

The second is a new variant, Hb Moscva, with the amino acid substitution $\beta 24$ (B6) Gly $\rightarrow$ Asp. It was found in a patient who suffered from myeloid leukaemia and who has since died, but it was possible to send her blood to Cambridge for further study. Incubation of the blood with brilliant cresyl blue⁶ resulted in the appearance of numerous Heinz bodies. The heat instability test⁷ and incubation with isopropanol⁸ both caused the formation of a red precipitate confirming the presence of an unstable haemoglobin. Subsequently an unstable haemoglobin was also found in the patient's half sister (by the maternal line), and the sister's son.

Hb Moscva migrated more rapidly towards the anode than Hb A on starch gel electrophoresis at pH 8.6 (ref. 9) and could be removed from the haemolysate, before electrophoresis, by heat precipitation⁷. There was only a single Hb A₂ fraction indicating that the abnormality was probably in the β , rather than the α chains. The proportion of Hb A₂ (4.1%) was slightly above the normal range (2.5–3.5%). The abnormal component, which represented 17% of the total haemoglobin, was isolated in the carbonmonoxy form on DEAE Sephadex¹⁰ and further purified, for structural studies, by paper electrophoresis¹¹.

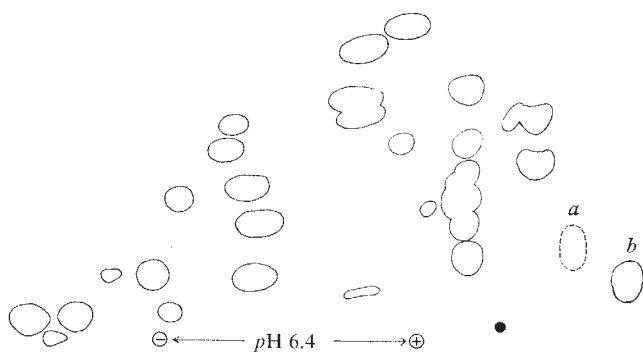


Fig. 1 Fingerprint of the soluble tryptic peptides of the globin from Hb Moscva. Electrophoresis at pH 6.4, 53 V cm⁻¹ for 1 h; ascending chromatography in pyridine-isoamyl alcohol-water (6:6:7, by volume) for 18 h. Peptides were located with 0.2% (w/v) ninhydrin containing 1% (v/v) pyridine and with the specific staining reagent (Sakaguchi) for arginine-containing peptides. ●, Origin; *a*, position of β A¹TpIII; *b*, β MoscvaTpXIII. The variant β TpIII was isolated by paper electrophoresis at pH 6.4 (61 V cm⁻¹, 1 h).

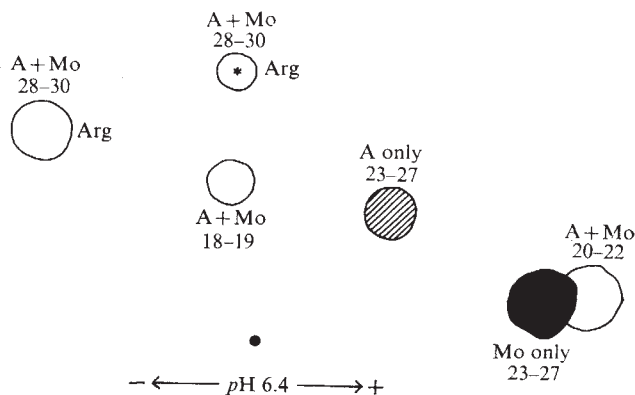


Fig. 2 Fingerprint of the thermolysin peptides of β^A TpIII (A) and β TpIII from Hb Moscva (Mo). Electrophoresis at pH 6.4, 53 V cm^{-1} for 45 min; ascending chromatography and location of peptides as in Fig. 1. The peptide $\beta^{\text{Moscva}}23-27$ was purified from $\beta 20-22$, for sequence studies, by paper electrophoresis at pH 9 (1% (w/v) $(\text{NH}_4)_2\text{CO}_3$, 44 V cm^{-1} , 1 h). ●, Origin.

*An electrically neutral peptide with an amino acid composition similar to that of the positively-charged peptide $\beta 28-30$ (Leu-Gly-Arg); it amounted to 6% of total $\beta 28-30$ and was thought to represent a minor reaction product, produced between ninhydrin and the guanidinium side chain of arginine $\beta 30$, during location of β TpIII after its preparation on paper.

On the fingerprint of the tryptic digest of Hb Moscva, prepared by standard techniques¹², peptide β^A TpIII ($\beta 18-30$) (a in Fig. 1) was replaced by a new, more negatively charged peptide (b in Fig. 1). The amino acid composition of the new peptide (Table 1) resembled that of β^A TpIII except for a substitution of one of the three glycine residues $\beta 24$, 25 or 29, (Table 2) by an aspartic acid residue. Asparagine is converted to aspartic acid during the hydrolysis which precedes amino acid analysis; a Gly $\rightarrow$ Asn substitution could, however, be excluded because of the increased negative charge of the variant peptide.

To determine which of the three residues had been replaced, the variant β TpIII was digested with thermolysin and the digest fingerprinted at pH 6.4. Comparison of the fingerprint with that from β^A TpIII (Fig. 2) showed that the peptide $\beta^A 23-27$ (Val-Gly-Gly-Glu-Ala) had been replaced by another, more negatively charged peptide, the amino acid composition of which (Table 1) indicated that one residue of glycine ($\beta 24$ or $\beta 25$) had been replaced by one of aspartic acid. Dansyl-Edman degradation¹³ showed the sequence $\beta 23-25$ to be Val-Asp-Gly and the amino acid substitution in Hb Moscva, therefore, to be $\beta 24$ (B6) Gly $\rightarrow$ Asp.

Table 1 Amino acid composition of the tryptic peptides $\beta 18-30$ and the thermolysin peptides $\beta 23-27$ from Hb A and Hb Moscva.

Amino acid	Peptide β TpIII ($\beta 18-30$)		Peptide $\beta 23-27$	
	A	Moscva	A	Moscva
Asp	2	3.0	—	0.9
Glu	2	2.0	1	1.0
Gly	3	2.0	2	1.0
Ala	1	1.2	1	1.0
Val	3	3.0	1	1.0
Leu	1	1.2		
Arg	1	1.1		

Peptides were hydrolysed with constant-boiling HCl for 18 h at 108° C in sealed evacuated tubes. After removal of the excess HCl in a rotary evaporator, the hydrolysates were analysed using a Locarte amino acid analyser.

Table 2 Amino acid sequence of the peptide β TpIII from Hb A and Hb Moscva

Residue No.	18	19	20	21	22	23	24	25	26	27	28	29	30
Helical No.	A15	B 1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B10	B11	B12
Residues													
Hb A	Val	Asn	↓Val	Asp	Glu	↓Val	Gly	Gly	Glu	Ala	↓Leu	Gly	Arg
Hb Moscva	Val	Asn	↓Val	Asp	Glu	↓Val	Asp	Gly	Glu	Ala	↓Leu	Gly	Arg

The arrows indicate the positions of hydrolysis by thermolysin (1 mg μmol^{-1} peptide); the bond between Glu 22 and Val 23 was only 52% hydrolysed in 5 h at 37° C but was completely split in 8 h at 50° C.

Measurements of the oxygen affinity of isolated Hb Moscva showed it to have a slightly lower oxygen affinity than Hb A (Fig. 3), but with a near normal Bohr effect and haem-haem interaction.

All known normal globin chains have a Gly in position B6, with four exceptions (α -chains of mouse NB and grey kangaroo, one of the midge and one of the plant haemoglobins)^{14,15}. M.F. Perutz has examined, with us, the possible consequences of the substitution in Hb Moscva using his atomic model of human haemoglobin. B6 is in a densely packed region of the molecule where a side chain could not be easily accommodated without forcing apart the B and E helices. In the three unstable haemoglobins Riverdale-Bronx¹⁶ Savannah¹⁷ and Moscva, the glycine residue $\beta 24$ (B6) is replaced by one of arginine, valine and aspartic acid, respectively. It is probable that these substitutions disturb the spatial relationships of the haem with the adjacent polypeptide chain; for example, J. Peisach observed that the EPR spectrum of met-Hb Riverdale-Bronx differs from that of met-Hb A (cited in ref. 16). Hb Savannah shows an increased dissociation into $\alpha\beta$ dimers¹⁷, suggesting that the $\alpha\beta 2$ contact may be indirectly affected.

It is not possible to predict how these substitutions may affect the oxygen affinity. Hb Riverdale-Bronx shows, in contrast to Hb Moscva, a higher oxygen affinity than HbA (P. A. L., un-

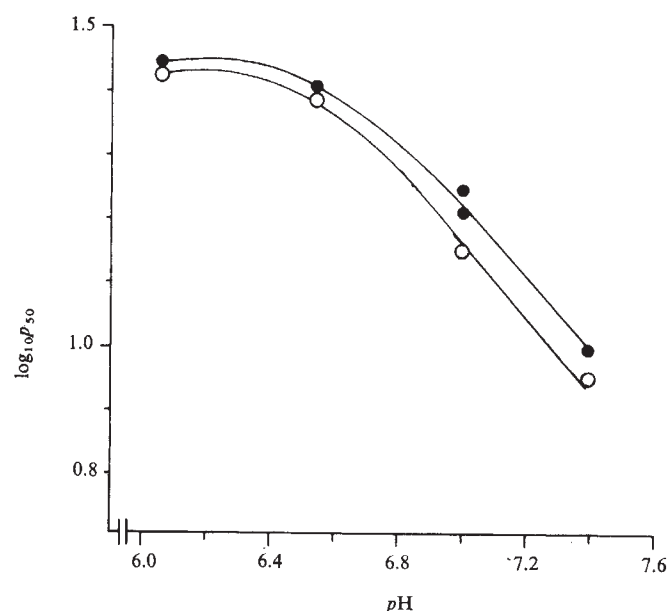


Fig. 3 Values of $\log_{10}p_{50}$ for, ○, Hb A and, ●, Hb Moscva at various pH values; p_{50} is the pressure of O_2 in mm Hg required to attain half saturation of the haemoglobin. The CO-Hb was concentrated to about 5% (w/v) by ultrafiltration at 4° C and then equilibrated with 0.05 M potassium phosphate buffer pH 8.6, by gel filtration on a 1.0×9.0 cm column of Sephadex G25 (coarse). The CO-Hb was converted to the oxy-form¹⁸ and oxygen dissociation curves were recorded by the automatic method of Imai *et al.*¹⁹ using 0.1% (w/v) haemoglobin solutions in 0.1 M potassium phosphate buffers of various pH values containing 0.5 mM EDTA. The measurements were made at a temperature of 23° C using monochromatic light of wavelength 474 nm. The values of p_{50} were determined from the dissociation curves and the values of n , the exponent of the Hill equation, were determined from the slope of the Hill plots. The curves were nearly parallel showing that the Bohr effect, which is represented by the slope of the curve $d(\log_{10}p_{50})/d(\text{pH})$, is the same for Hb Moscva and Hb A.

published) but both have a near-normal Bohr effect and haem-haem interaction.

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Note added in proof: After this manuscript was submitted, we identified a third unstable haemoglobin from Russia. Its substitution was $\beta 106$ (G8) Leu-Pro. This variant has been found independently in the United States in two unrelated persons as Hb Casper²⁰ and in the United Kingdom in one individual as Hb Southampton²¹.

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Endocytotic formation of rat brain synaptic vesicles

THE present knowledge and theories regarding the fate of synaptic vesicles was reviewed by Holtzman *et al.*¹. Using electron microscopy it has been found that a marker protein (horseradish peroxidase) was incorporated into vesicles of frog neuromuscular junctions by microinvagination of the synaptic plasma membrane²⁻⁵ and also into brain synapses⁶. Heuser and Reese² have put forward a model postulating recirculation of synaptic vesicle structural materials. Thus, during release of neurotransmitter into the synaptic cleft the vesicle membrane should fuse with the presynaptic membrane, and then vesicles could be reformed by invaginations of the synaptic plasma membrane distant from the synaptic cleft.

We have investigated whether synaptic vesicles could be labelled after intracerebral injection of a marker protein. Rats were injected intracisternally with bovine serum albumin (BSA) and after isolation of the synaptic vesicle fraction and specific quantitative assay of its BSA content, the synaptic vesicles were found to be enriched with the label in an endocytotic process dependent on time and affected by barbiturates.

Thirty-five-day-old rats in groups of eight were injected with 2.2 mg BSA in 10 μ l 0.9% NaCl, into the cisternae magna by the suboccipital route. The rats were anaesthetised with equal volumes of oxygen and carbon dioxide during the injection. They recovered less than half a minute after removal of the anaesthetic. After 5, 120 or 240 min the rats were decapitated. Their brains were homogenised in isotonic sucrose: and by sedimentation rate separations crude synaptosomal-mitochondrial subfractions (cmf) were produced. These were osmolyzed in water and separated on a density gradient by ultracentrifugation^{7,8}. The 0.2/0.4 M sucrose density gradient interface and the 0.4/0.6 M interface were removed, diluted with water and centrifuged to give synaptic vesicles (ves) and synaptic vesicles heavily contaminated with microsomes (m-ves), respectively. The ves and m-ves layers have been identified by electron microscopy⁹ and by analysis of an antigen characteristic of vesicles⁷. No differences were found between the three labelling periods with respect to the amount of vesicle antigen. The brain homogenate (hom) containing both free and bound BSA, and the subcellular fractions cmf, ves and m-ves containing only bound BSA were solubilised in Triton X-100 and analysed for BSA content by rocket immunoelectrophoresis.

Figure 1 shows that the synaptic vesicle subcellular fractions are enriched in BSA both compared with the parent cmf fraction and the microsome-contaminated m-ves fraction. The enrichment of BSA in the synaptic vesicle fraction was greatest at 120 min labelling time, but the decrease with 240 min labelling time paralleled the decrease in hom and cmf. When BSA was added directly to prepared, until then unlabelled, hom and cmf fractions, the specific BSA content in subsequent prepared ves fractions was less than 0.08 μ g BSA per mg protein (lower detection limit), ruling out unspecific adhesion to subcellular particles.

We have compared the specific BSA content in the synaptic vesicle fraction between control groups, and groups of rats

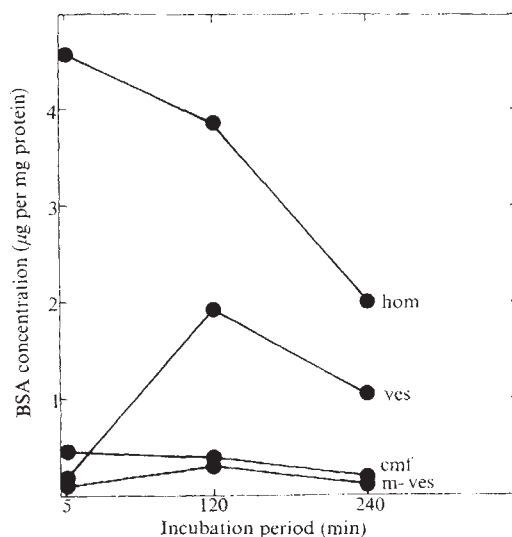


Fig. 1 Specific concentration of suboccipital injected BSA in fractions of rat brains at different incubation periods. Subcellular particles were solubilised in 2% Triton X-100, 10 mM phosphate, 1 mM EDTA and 1% Trasylol (a protease inhibitor), adjusted to pH 8.5. After 2 h at 4°C the supernatant from an ultracentrifugation at 6,000,000g $\times$ min was used for rocket immunoelectrophoresis. Here we used 0.17 μ l rabbit anti-BSA cm⁻², detecting between 5 and 400 ng BSA in samples of 20 μ l solubilised material¹⁰.

anaesthetised with barbiturate during a labelling period of 120 min. The specific contents of BSA in ves from rats treated with barbiturate (Nembuto) were only 66% of that of the controls.

As the vesicles were enriched compared with both parent (cmf) and sister (m-ves) fractions assayed, the BSA-containing particles must be an integral part of the ves fraction. The BSA uptake may be explained by pinocytotic *de novo* formation of the vesicles from the synaptic plasma membrane as well as by transitory fusion of preformed vesicles with the synaptic membrane during release of transmitter into the synaptic cleft¹¹. But taken together with the electron microscopic observations of micropinocytosis in the central nervous system, these results indicate that at least a part of the synaptic vesicles have been formed or reformed from the synaptic plasma membrane in an endocytotic process. Anaesthesia decreased the BSA content of the vesicles to 66% possibly by impeding vesicle formation. It has also been shown that electrical stimulation of peripheral nerves increased the endocytotic uptake of horseradish peroxidase⁹. Thus, it should be possible to include the quantitative measurement of endocytotic formation of brain synaptic vesicles in the armament of the neuropharmacologist.

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concentrations from untrained animals. Overtraining of the donor animals also has been shown to have marked effects on the degree of transfer in recipient animals⁹.

The avoidance learning task in our experiments was similar to the task required of fish in the shuttle-box described by Horner *et al.*¹⁰ except that two coloured lamps served as the conditioned stimuli. The four shuttle-boxes were rectangular plastic aquaria (78×15×15 cm) equipped with trapezoidal-shaped barriers dividing the boxes into two compartments. Each box had graphite electrodes along the sides to deliver an electric shock. Photo cells at each end of the barrier monitored the response and registered the side of the shuttle-box containing the fish for each trial. The task for the fish was to learn to anticipate a mild (5 V a.c.) electric shock by swimming over the barrier to the other compartment whenever one of two coloured signals (red or green) was presented. All stimulus and response contingencies were controlled and recorded by automated circuitry.

The two experiments below differed in the consequences of responding to the wrong signal, the amount of training given the donor animals and the number of groups of recipient animals. In the first experiment, fish which would later become recipients of the nucleic acid extract from donor animals were trained in a red-green avoidance discrimination. The red signal was presented for 20 s, after which a pulsed electric shock was delivered. Whenever the green signal was presented, it remained on for 30 s and no shock was delivered, regardless of the fish's reaction to it. We designate this as a R+G- task where response to green was punished. All fish in both experiments were obtained from local suppliers and were 7-8 cm long. They were housed for one week in a 400 l aquarium and later transferred to individual 6 l aquaria which were supplied with filters. Water temperature was maintained at 20° C.

In the first experiment 74 donor fish (*Carrasius auratus*) were trained in a R+G- discrimination and seven to a G+R- task for 3 d (100 trials each day, 50 red, 50 green,

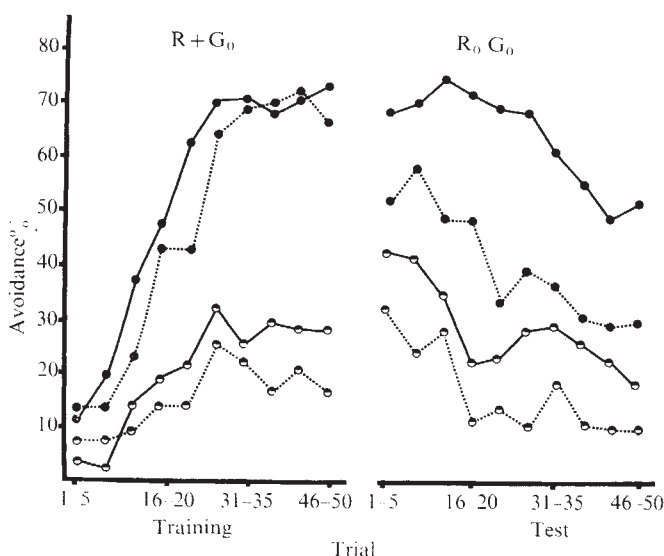


Fig. 1 Action of nucleic acid extracts on two groups of goldfish trained in a red-green avoidance learning task (R+G₀). The upper curves on the left (solid black dots) show the percentage avoidance to the positive red stimulus while the bottom two curves on the left (black and white dots) show the response to the incorrect green stimulus. The effect of the dissimilar injection is shown by the set of curves on the right when the same fish were tested under extinction conditions (R₀G₀). The solid line fish were injected with extract from R+G- trained donors while the broken line fish were injected with G+R- trained extract.

Chemical transfer of learned colour discrimination in goldfish

THE literature describing chemical transfer of learned information has been characterised by contradictory findings during the past ten years¹⁻³.

We have, however, recently managed to obtain reliable and repeatable results with goldfish, and we report below two experiments which were designed to test the specificity of chemical information transfer.

The reliability and direction of transfer has been reported to be influenced by the amount and type of extract injected, the amount of training of the donor and recipient animals and the time between injection and test⁴⁻⁷. These same variables have been important in our own work with goldfish⁸. We have shown, for example, that very small concentrations (1 µg) of nucleic acid extracts from trained donors produce stronger transfer effects than higher concentrations, when compared with injections of the same

randomly presented). A large number of donor animals were trained in order to have enough extract for dose-response studies. Each trial consisted of the onset of the red or green stimulus lamp on the side of the box containing the fish. When the positive stimulus (R+ or G+) was presented, a 5 V a.c. pulsed shock was delivered (1 s^{-1} , 80 ms duration) 20 s later, unless the fish swam over the barrier into the other compartment. When the negative stimulus (R- or G-) was presented, the animal could avoid shock by staying in its compartment. If the animal responded during the negative stimulus presentation, it was shocked until it returned to the original side. In the R+ or G+ trials, the shock was limited to 10 s when the fish failed to escape. The intertrial interval was 30 s.

Twenty-four hours after this 3 d training period, the fish were decapitated, their brains extracted and placed in liquid nitrogen. The hot-phenol procedure⁸ was used to extract nucleic acids from the brain tissue. This method yielded a RNA/DNA mixture of about 300 to 400 μg per fish brain. Only fish that had reached at least the 50% avoidance level to the positive stimulus were used in the extraction procedure.

Two groups of 23 fish each, designated to become recipients, were trained to the R+G₀ discrimination described above for one day or 100 trials (50 red, 50 green). Immediately after this training, each fish was injected with 1 μg of extract in 10 μl of saline. The injection was intracranial into the large cranial cavity over the brain. Using a blind procedure, one group was injected with extract from the R+G- trained donors and the other with G+R- extract. They were tested 24 h later for 100 trials under extinction conditions (R₀G₀).

Both groups reached about the 70% avoidance level in responding to the positive stimulus (R+) at the end of training (Fig. 1). Although there was some generalisation to the G₀ stimulus (about 25% responding), discrimination is obvious. The effect of the intracranial injection from differentially trained donors was apparent in the test trials on the next day. Fish receiving extracts from similarly trained donors remained at a relatively high level during the extinction trials while fish receiving extract from the G+R+ or dissimilarly trained donors showed a much lower level of performance. This difference is statistically significant at the $P < 0.01$ level.

Although the results of the first experiment show a dramatic injection effect, they can only be regarded as suggestive evidence for specific information transfer because of a difference in performance level of the donor animals in the R+G- and G+R- tasks. Since the R+G- discrimination is easier to learn, it can be argued that the observed negative transfer may be due to the different number of shocks received by the G+R- donor animals. The complete factorial design of the second experiment makes this possibility highly unlikely.

In the second experiment, two groups of donor animals were trained as before except that an overtraining procedure was used. Overtraining of the donors has been shown to maximise transfer in a single-stimulus avoidance training situation. The advantage of overtraining is that it equalises asymptotic performance of the R+G- and G+R- donor groups although it does not ensure that both groups receive the same number of shocks since the R+G- animals reach their asymptotic level (90–95%) faster than the G+R- donors. They were trained either on a R+G- or a G+R- task for 5 d (100 trials d^{-1}), rested for 2 d and further trained for 2 d. Immediately after this training their brains were extracted and processed as before. All donor fish had reached at least the 50% avoidance level.

Four groups of fish, designated as recipients, were trained for a 1 d, 100 trial session. There were two R+G- groups and two G+R- groups, each with 15 fish. Immediately

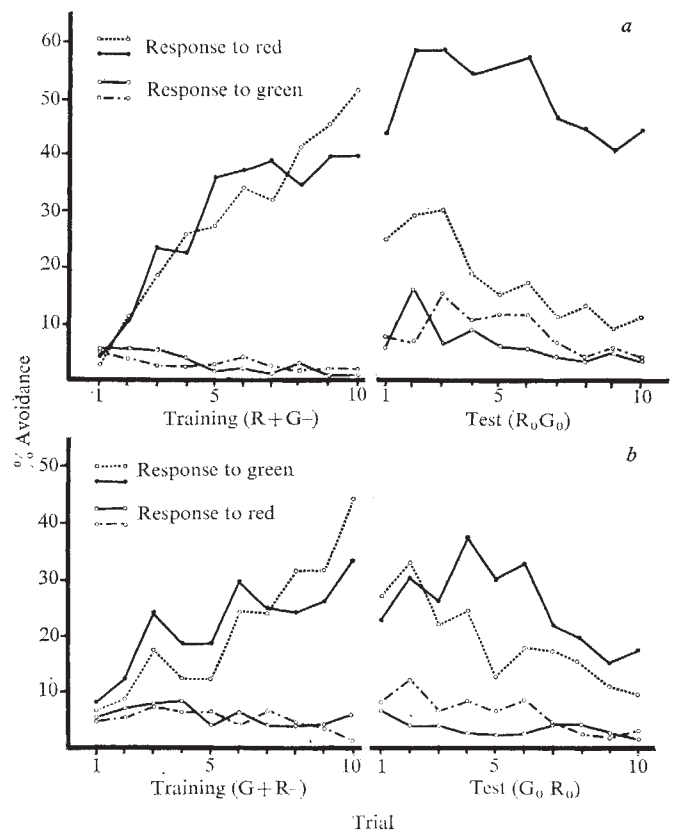


Fig. 2 *a*, Action of nucleic acid extracts on two groups of goldfish trained in a red-green avoidance learning task (R+G-): the upper two curves on the left show the percentage avoidance to the positive red stimulus while the bottom two curves on the left show response to the incorrect green stimulus. The effect of the dissimilar injection is shown in the right set of curves where the same fish were tested under extinction conditions (R₀G₀). The solid line fish were injected with extract from R+G- trained donors while the broken line fish were injected with extract from G+R- trained donors. *b*, Action of nucleic acid extracts on two groups of goldfish trained in a green-red avoidance learning task (G+R-). The upper two curves on the left show the percentage avoidance to the positive green stimulus while the bottom two curves on the left show the response to the red stimulus. The effect of the dissimilar injection is shown in the set of curves to the right when the same fish were tested under extinction conditions (G₀R₀). The solid line fish were injected with G+R- trained extract while the broken line fish were injected with extract from R+G- trained fish.

after this training, each animal was intracranially injected with 1 μg of extract from donor animals that were similarly or dissimilarly trained. Twenty-four hours after this injection all animals were given 100 test trials under extinction conditions (R₀G₀).

Figure 2 shows the training and test performance of the four recipient groups. The divergent effects of the injections are apparent for both red-trained and green-trained groups but are particularly striking for the R+G- groups (Fig. 2*a*). Fish receiving extract from animals trained in the identical task improved in performance, while those receiving extract from the opposite trained donors show a marked decline.

Figure 2*a* shows that the difference between the groups in the test trials was due to both the positive transfer on the R+G- trained/R+G- injected group and a negative transfer on the R+G- trained/G+R- injected group. This distinction is not observed in the G+R- recipients where the major part of the difference after injection is caused by the decline in performance of the G+R- trained/R+G- injected group.

The statistical significance of these findings was assessed using a two-way analysis of variance.

by a five-way analysis of variance with repeated measures on three factors. The difference in performance to the positive stimulus between groups receiving extract from similarly or dissimilarly trained donors is significant at the $P < 0.001$ level. Not only is response to the positive stimulus affected by the type of extract, but there is also a tendency for the response to the negative stimulus to be affected as well, although to a much lesser degree.

We are puzzled by the apparent interaction with colour *per se*. The major effect is seen with the red-trained groups. It is possible that this difference is associated with the relatively greater difficulty fish have in learning the avoidance response in the G+R- task. This colour-sensitivity difference between red and green performance has been observed in all studies of the red-green discrimination in this laboratory. The difference persists even when the two stimuli are equated for intensity. An additional control group with extracts from donors trained on an avoidance task with an entirely different set of stimuli might have added to our understanding and assessment of the differences in each pair of subgroups.

The results of both these experiments are consistent with the hypothesis that the extract contains chemically coded specific information which facilitates or inhibits performance. These results are also consistent with other data from this laboratory where similar designs were used in a single stimulus task⁹. Two groups of fish were trained to make avoidance responses to a light-onset signal. They were then injected with extract from donors that were similarly (light-onset) or dissimilarly (light-offset) trained. The test trial performance showed the same divergence in performance as observed here.

In another complete factorial study we conducted, where the recipient animals were overtrained for 3 d (also a red-green task), the striking difference observed in the above two experiments failed to appear. Although a positive transfer is more difficult to achieve in animals already performing at the 80–85% level after 3 d of training, a negative transfer, as was found in the first experiment, is possible but does not appear when the recipients are overtrained. It is possible that well-consolidated information is not as susceptible to chemical interference as has been observed in the puromycin consolidation studies of memory^{11–12}.

We are planning experiments to further characterise the nucleic acid extracts responsible for the information transfer.

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Influence of local hydrophobic environment on acid dissociation constants of coordinated water molecules

THE hydration of carbon dioxide by Zn(II) carbonic anhydrase is thought^{1,2} to occur through a mechanism in which a hydroxyl group coordinated to the zinc atom has an important function. As a consequence, the pK of the conjugate acid coordinated water molecule has been the subject of some discussion^{2,3}. In Zn(II) (ref. 4) and Co(II) (ref. 5) carbonic anhydrase, the water molecule bound to the metal ion, apparently has a pK in the range 6.9–7.9, which is two units lower than the pK range quoted⁶ for the first protolysis of $[Zn(H_2O)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$. (The pK values quoted for $[M(H_2O)_6]^{2+}$ exhibit a considerable variance and have been determined under a variety of experimental conditions. When $M = Co, Ni, Cu$ and Zn mean pK values of 9.8, 10.3, 7.8 and 9.5, respectively, are derived from the range of values quoted at zero ionic strength and at 298 K (pK values for all four metal ions in 1 M $NaClO_4$ are not available).)

Structural studies⁷ show that the zinc atom in Zn(II) carbonic anhydrase is situated at the bottom of a cleft, lined with hydrophobic groups, in the protein molecule, and also that it is tetrahedrally coordinated by three imidazole groups and one water molecule. It has been postulated that this local hydrophobic environment is largely responsible for the decreased pK of the coordinated water molecule^{2,3}. Although the variation of the pK of coordinated water with the metal ion character and environment is well known^{8,9}, there seems to be no report of a study in which this postulate may be tested.

Here we report a study in which the environment of a water molecule is changed from hydrophilic to hydrophobic for a range of metal ions, whilst the ligand donor atoms and metal ion coordination number remain constant and the coordination geometry almost so.

Divalent cobalt, nickel, copper and zinc all form stable 1 : 1 complexes with both 2, 2', 2''-triaminotriethylamine (tren) (ref. 10) and 2, 2', 2''-tri (N, N-dimethylamine) triethylamine (Me_6tren) (ref. 11) in aqueous solution. The complexes are five coordinate^{12–14} with the general formula $[MtrenH_2O]^{2+}$ and $[MMe_6trenH_2O]^{2+}$ with the exception of the species $[Ni tren(H_2O)_2]^{2+}$. An examination of space filling models based on the known solid state structures of the¹⁵ $[M trenNCS]^+$ and $[MMe_6trenBr]^+$ ions reveals that the coordinated water molecule in $[M trenH_2O]^{2+}$ is closely adjacent to the hydrophilic primary amine groups of the tren ligand, whereas the coordinated water molecule of $[MMe_6trenH_2O]^{2+}$ is sterically crowded by the hydrophobic methyl groups of the Me_6tren ligand (Fig. 1). Thus, these complexes provide an opportunity for the examination of both the effects of the metal ion and of the change of environment on the pK of the coordinated water molecule.

The complexes undergo protolysis as follows:

$$[M trenH_2O]^{2+} + H_2O \rightleftharpoons [M trenOH]^+ + H_3O^+$$

$$[MMe_6trenH_2O]^{2+} + H_2O \rightleftharpoons [MMe_6trenOH]^+ + H_3O^+$$

Apparent pK values were determined by sodium hydroxide titration, under nitrogen, of 5×10^{-3} M complex solutions in aqueous 1M sodium perchlorate media, using a Radiometer combined glass and calomel electrode, and a Radiometer

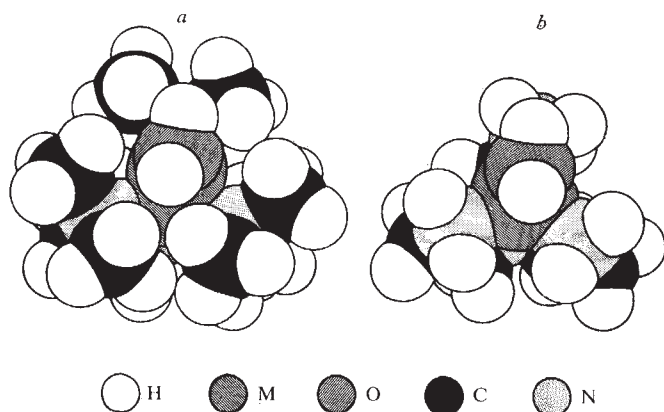


Fig. 1 Space filling models of $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ (a) and $[\text{MtrenH}_2\text{O}]^{2+}$ (b).

PHM4 or PHM26 pH meter. Sodium hydroxide was added with an Agla microsyringe. Complex solutions were prepared in carbon dioxide-free water by the addition of equimolar amounts of metal perchlorate salt and polyamine ligand solution; except when the solid complex $[\text{MMe}_6\text{trenClO}_4]\text{ClO}_4$ ($\text{M} = \text{Ni}, \text{Co}, \text{Cu}$) was used directly. (The titration data were consistent with rapid dissociation of the coordinated perchlorate to produce $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ upon dissolution.) Titration curves were corrected for the concentration of uncombined hydroxyl ion by reference to a titration of 1M sodium perchlorate alone. Apparent pK values were calculated from plots of pH against $\log ([\text{salt}]/[\text{acid}])$ by a least squares regression analysis. Each complex was titrated in duplicate at 288 K, 298 K and 308 K thus facilitating the computation of ΔH° and ΔS° for the protolysis reaction. The results obtained are summarised in Table 1.

In Fig. 2 the pK (298 K) values for the $[\text{MtrenH}_2\text{O}]^{2+}$ and $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ series show similar dependences upon the nature of the central metal ion, the general trends in which persist for each series over most of the solution liquid range as indicated by the thermodynamic data. The pK for six coordinate $[\text{Ni tren}(\text{H}_2\text{O})_6]^{2+}$ cannot be strictly compared with those of its five coordinate cobalt, copper and zinc analogues. The titration data, however, show the first pK for this species to be greater than 11.0, and this datum is shown by the broken box in Fig. 2. The $\text{M}-\text{Br}$ bond distances¹³ for $[\text{MMe}_6\text{trenBr}]^+$ are also plotted in Fig. 2 and there exists a strong similarity between the dependence of these distances upon the metal ion (which has been explained in terms of d orbital occupancy¹³) and the variation in pK values exhibited by the $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ series. On the assumption that the $\text{M}-\text{OH}_2$ distances exhibit a similar variation it would seem that increasing metal ion attraction for the coordinated water molecule results in a decrease in pK . It is noteworthy that there is no correlation between pK value and

any of the $\text{M}-\text{N}$ distances¹³ in the $[\text{MMe}_6\text{trenBr}]^+$ series.

The pK variation between the $[\text{MtrenH}_2\text{O}]^{2+}$ and $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ series might arise either because of differences in the environment of the coordinated water molecule in each case, or because of differences in electron donation to the central metal atom between the $-\text{NH}_2$ groups of tren and the $-\text{N}(\text{CH}_3)_2$ groups of Me_6tren , or a combination of these two factors. The crystal field splitting for $[\text{Co trenH}_2\text{O}]^{2+}$ has been shown to be greater than that of its methylated analogue¹², and on this basis the greater electron donation to the metal ion in the $[\text{MtrenH}_2\text{O}]^{2+}$ series might result in a higher pK for these complexes than for the $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ series. This is the trend observed and consequently it is evident that the pK variation cannot be attributed solely to variation of the local environment of the coordinated water molecule in the two series, although it seems that this last factor is of major importance.

A reasonable linear free energy relationship (LFER) characterised by an isoequilibrium temperature of 269 ± 16 K, exists (Fig. 3) for the thermodynamic data of Table 1. This LFER indicates that a single major factor accounts for the difference between the entropy dominated $[\text{MtrenH}_2\text{O}]^{2+}$ pK values and the enthalpy dominated $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ pK values. The systematic displacement of the data about the LFER regression line is a consequence of ΔH° and ΔS° becoming increasingly positive in the order $\text{Cu} < \text{Co} < \text{Zn}$ for both series of complexes, and indicates the specific metal ion perturbation of the major LFER relationship. The isoequilibrium temperatures for the isometallic $[\text{MtrenH}_2\text{O}]^{2+}$ and $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ pairs are 239 K (Co), 261 (Cu) and 250 K (Zn).

The thermodynamic differences between the two series of complexes are summarised in Table 2. If, following the method of Hepler¹⁷, ΔH° and ΔS° are considered as sums of internal contributions, arising from interactions within the metal complexes, and external contributions arising from interactions between the complex and the solvent, one may write:

$$\begin{aligned}\Delta H^\circ &= \Delta H^\circ_{\text{int}} + \Delta H^\circ_{\text{ext}} \\ \Delta S^\circ &= \Delta S^\circ_{\text{int}} + \Delta S^\circ_{\text{ext}}\end{aligned}$$

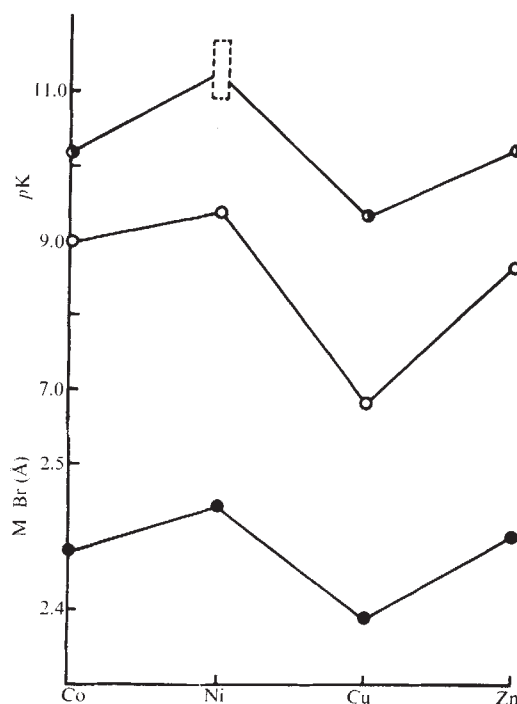


Fig. 2 Apparent pK values of $[\text{MtrenH}_2\text{O}]^{2+}$ (●) and $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ (○); and the $\text{M}-\text{Br}$ distances in $[\text{MMe}_6\text{trenBr}]^+$ (●) when $\text{M} = \text{Co}, \text{Ni}, \text{Cu}$ and Zn .

Table 1 Apparent thermodynamic data at 298 K for the acid dissociation of a single water molecule coordinated to tren and Me_6tren complexes

Complex	$pK \pm (\text{s.e.})$	$\Delta H^\circ \pm (\text{s.e.})$ kJ mol^{-1}	$\Delta S^\circ \pm (\text{s.e.})$ $\text{J K}^{-1} \text{mol}^{-1}$
$[\text{Co trenH}_2\text{O}]^{2+}$	10.22 ± 0.01	$+ 0.9 \pm 2.7$	-192.7 ± 9.1
$[\text{Cu trenH}_2\text{O}]^{2+}$	9.37 ± 0.01	-13.6 ± 1.9	-225.0 ± 6.4
$[\text{Zn trenH}_2\text{O}]^{2+}$	10.26 ± 0.02	$+11.9 \pm 1.9$	-156.5 ± 6.4
$[\text{CoMe}_6\text{trenH}_2\text{O}]^{2+}$	8.80 ± 0.04	$+33.9 \pm 1.9$	-54.5 ± 6.4
$[\text{NiMe}_6\text{trenH}_2\text{O}]^{2+}$	9.53 ± 0.01	$+33.9 \pm 1.9$	-68.7 ± 6.4
$[\text{CuMe}_6\text{trenH}_2\text{O}]^{2+}$	8.52 ± 0.01	$+28.8 \pm 1.9$	-66.5 ± 6.4
$[\text{ZnMe}_6\text{trenH}_2\text{O}]^{2+}$	9.00 ± 0.01	$+49.2 \pm 1.9$	-7.2 ± 6.4

Further, Pitzer¹⁸ has shown that for the dissociation of a weak acid $\Delta S^\circ_{\text{int}} \approx 0$. Thus, the differences in ΔS° between equivalent members of the two series of complexes are most probably entirely due to differences in the external contributions to the standard entropies of protolysis. Examination of Table 2 shows that the values of $\Delta S^\circ_{\text{Me}_6\text{tren}} - \Delta S^\circ_{\text{tren}}$ are very similar for Co, Cu and Zn; indicating that the differences between $[\text{MtrenH}_2\text{O}]^{2+}$ and $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ are caused by a similar change in environment for each metal.

Table 2 Differences in apparent thermodynamic quantities between Me_6tren and tren complexes

Metal	$pK_{\text{Me}_6\text{tren}} - pK_{\text{tren}}$	$\Delta H^\circ_{\text{Me}_6\text{tren}} - \Delta H^\circ_{\text{tren}}$	$\Delta S^\circ_{\text{Me}_6\text{tren}} - \Delta S^\circ_{\text{tren}}$
Co	-1.42	33.0 ($\pm$ 4.6)	138.2 ($\pm$ 15.5)
Cu	-0.85	41.4 ($\pm$ 3.8)	158.5 ($\pm$ 12.8)
Zn	-1.26	37.3 ($\pm$ 3.8)	149.3 ($\pm$ 12.8)

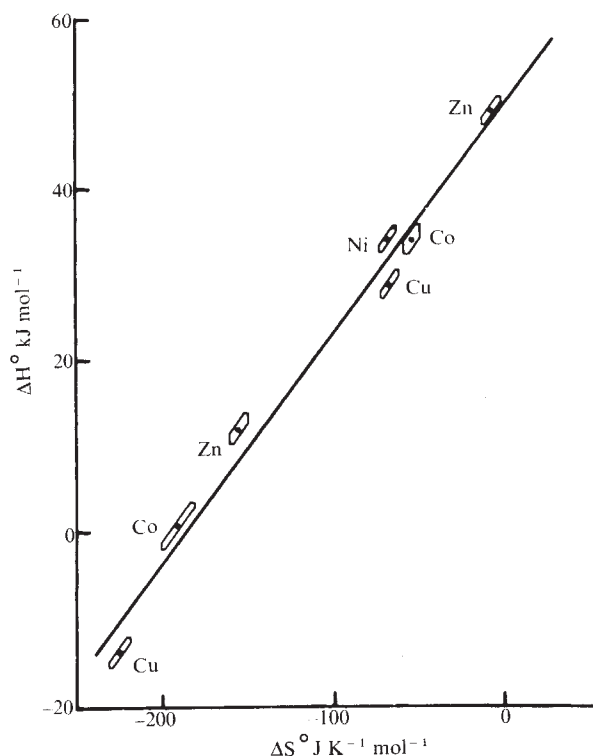


Fig. 3 The linear free energy relationship for the protolysis of $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ (upper set of points) and $[\text{MtrenH}_2\text{O}]^{2+}$ (lower set of points) when $M = \text{Co}, \text{Ni}, \text{Cu}$ and Zn . The error estimates were calculated by the method of Mandel and Linnig²².

The most probable environmental difference between $[\text{MtrenH}_2\text{O}]^{2+}$ and $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ is in the degree of ordering of solvent water molecules close to these complexes. It seems from two partly related considerations that the degree of solvent water ordering about $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ is likely to be the greater. First, the surface of $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$, with the exception of the coordinated water molecule, is composed of hydrophobic alkyl groups—a situation generally considered to engender the formation of an ordered 'ice-like' structure in

solvent water adjacent to such a surface^{19,20} as is observed in the vicinity of the zinc atom in carbonic anhydrase⁷. By contrast the hydrophilic amine groups of $[\text{MtrenH}_2\text{O}]^{2+}$ seem unlikely to affect the adjacent water structure significantly¹⁹. Second, the charge density on the surface of the two complexes, particularly in the vicinity of the coordinated water molecule seems likely to be greater in the case of $[\text{MtrenH}_2\text{O}]^{2+}$ as this species is smaller (Fig. 1) and also because of the polarity of the amine groups. According to Frank and Wen¹⁹, large ions with a low surface charge density are surrounded by a layer of water, disordered to an extent approximately proportional to the charge density (region B in the terminology of Frank and Wen¹⁹) as a consequence of two competing influences; the ionic charge solvent water dipole interaction, and the structural orientating influence of neighbouring bulk water molecules acting upon solvent water molecules adjacent to the ion. It seems that as a result of its greater surface charge density and because of the hydrophilic nature of the amine groups, solvent water adjacent to $[\text{MtrenH}_2\text{O}]^{2+}$ will be less ordered and the decrease in entropy greater upon protolysis than will be the case for $[\text{MMe}_6\text{trenH}_2\text{O}]^{2+}$ consistent with the observed trend in ΔS° .

These conclusions lend some support to the suggestion that the low pK values for the coordinated water molecule in carbonic anhydrase² and also for other weak acid groups conjugated to proteins²¹ are, in part, a consequence of their hydrophobic environment. It should be noted, however, that the systems studied here are structurally simple and that the relative importance of hydrophobic effects in these systems may differ considerably from the importance of such effects in the protein systems.

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Prolongation of skin allografts after oral application of ALS in rats

THE potency of anti-lymphocytic serum (ALS) in prolonging skin allografts has been well investigated. Four different routes of administration are being used: intravenous¹, intraperitoneal², intramuscular³ and subcutaneous⁴. Every route has its own advantages and disadvantages from the immunological and clinical point of view and these have been discussed elsewhere^{5,6}. Oral application of ALS was never tried because it was assumed that intact proteins like gamma globulins are enzymatically metabolised before they pass through the intestinal wall. But we shall demonstrate, that even oral application of ALS can prolong the survival time of skin allografts.

Two different series of experiments were performed, using altogether 65 white male colony-bred Sprague-Dawley rats, weighing 250 g. All animals were grafted with skin from black inbred BD-6 rats. In the first series, animals were fed 1 ml ALS daily, until graft rejection was completed and controls were fed with normal rabbit serum (NRS). In the second series animals were treated orally with 1 ml ALS or 1 ml NRS on days 1, 3 and 5, only. Feeding was by a polyethylene tube placed into the stomach. The effect of oral ALS application was compared with the effect of intraperitoneal administration of ALS or NRS. One group of rats remained entirely untreated. For statistical analysis mean values, standard error of the mean (s.e.m.), and *P* values according to student's *t* test were calculated.

ALS was produced in rabbits by 'two pulse' injection of lymphocytes from the thoracic duct and thymus of rats. The first pulse was applied together with complete Freund's adjuvant. The lymphocytotoxic titre of ALS was 1:64, and the haemagglutination titre 1:4, after one absorption with rat erythrocytes. ALS and NRS both had a protein concentration of 50 mg ml⁻¹.

The results are set out in Table 1. The mean survival time (MST) of skin grafts in rats without any treatment was about 10 d. Intraperitoneal as well as oral application of NRS did not prolong the MST of skin grafts significantly (*P* < 0.1). As expected, i.p. administration of ALS either every day or just on days 1, 3 and 5 increased the MST of skin allografts significantly (*P* < 0.001). But the daily oral application of ALS also prolonged the MST to 26.5 ± 1.9 d; this was 13 d longer than that for control animals treated in the same manner with NRS. When the high dosage of ALS of 1 ml daily was reduced to 1 ml on days 1, 3 and 5, this caused a decrease of the MST from 26.5 ± 1.9 d to 23.4 ± 1.8 d. Nevertheless, skin allografts survived significantly longer (*P* < 0.001) after oral application of ALS than after oral application of NRS, the difference being 10 d.

Table 1 Prolongation of skin allografts after oral and i.p. application of ALS

Group	No.	Treat-ment	Route	Dose (1 ml)	MST* ± s.e.m. (d)	Median ST† (d)
Series 1						
1	9	ALS	oral	Daily	26.5 ± 1.9	23.8 ± 1.4
2	6	NRS	oral	Daily	13.6 ± 1.7	10.3 ± 0.3
Series 2						
3	10	ALS	oral	Days 1, 3, 5	23.4 ± 1.8	19.2 ± 1.9
4	7	NRS	oral	Days 1, 3, 5	13.1 ± 0.6	12.2 ± 0.75
Controls						
5	9	ALS	i.p.	Daily	31.7 ± 1.2	28.5 ± 1.2
6	5	NRS	i.p.	Daily	12.8 ± 1.1	11.0 ± 0.5
7	10	ALS	i.p.	Days 1, 3, 5	18.6 ± 0.3	17.8 ± 0.2
8	5	NRS	i.p.	Days 1, 3, 5	10.6 ± 0.3	9.6 ± 0.3
9	14	—	—	—	10.1 ± 0.2	9.6 ± 0.2

* Mean survival time.

† Median survival time.

The oral route of application seems to be less effective than the i.p. route when ALS is given daily. The i.p. application of ALS on days 1, 3 and 5 prolonged the MST of skin allografts only to 18.6 ± 0.3 d, whereas after oral treatment, allografts were rejected after 23.4 ± 1.8 d. A statistical analysis, however, does not show significant differences between the groups.

The prolongation of skin allografts after oral application of ALS contradicts the generally held opinion that gamma globulins are metabolised on their way through the gut by digestive enzymes^{7,8}. Providing the effect of ALS depends on an interaction with lymphocytes or with the graft, the significant prolongation of the MST after oral application can be explained by a partial absorption of intact protein molecules. Since BSA (refs 9 and 10), horseradish peroxidase¹⁰ or kallikrein¹¹ are known to be absorbed without biochemical or immunological alterations the absorption of intact gamma globulin is perhaps not surprising. The alternative hypothesis, that orally administered ALS causes lesions in the intestinal wall which allow protein molecules to leak through, is made highly improbable by histological and macroscopic observations on the intestine. It is, nevertheless, conceivable that ultrastructural changes in the gut wall facilitate the penetration of unaltered gamma globulins. It is also possible that lymphocytes normally invading the lumen of the gut¹² are exposed to ALS there. By this means ALS might reduce the absolute number of lymphocytes without penetrating the intestinal wall.

Preliminary studies in rats and dogs have shown that it is possible to detect xenogeneic globulins in the blood of recipients using Ouchterlony's technique and Sephadex radiochromatography, following oral application of ALS. It is therefore possible that a proportion of unaltered gamma globulins does pass through the intestinal wall. But rats have less proteinase in their gut than dogs and man; this means that ALS is metabolised less in the small intestine of rats than in that of humans. Consequently, more ALS might be absorbed in rats and this may explain the success in prolonging skin allografts after oral treatment.

Apart from this theoretical interest, the oral route may become important for the clinical application of ALS, because the antibody production of orally treated animals seems to be markedly reduced. Whereas the i.p. application of ALS causes the formation of precipitating anti-horse serum protein antibodies in all recipients, oral administration causes precipitating antibodies in only 10% of rats after 14 d of treatment.

We thank Professor L. Brent for criticism.

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matters arising

Nonradioactive silver

SIR,—Lindner *et al.*¹ described the detection of small amounts of radioactive silver isotopes (^{108m}Ag and ^{110m}Ag) in silver bars from an eastern European source. They suggested that the activity may have originated from any one of several causes: nuclear mining, that is, the breaking up of rock before the removal of the ore, using nuclear explosions; neutron irradiation of the ore after it was mined; the introduction of silver isotopes into the melted silver during processing; or irradiation of the silver bars.

Another possibility has been suggested by Boyle². An intimate contact of silver, uranium and light elements such as boron, might produce, through (α, n) reactions, enough neutrons to give measurable events of ^{108m}Ag ^{110m}Ag. This phenomenon could occur in uranium deposits of the vein type, which are found in eastern Europe.

We have checked this speculation by counting specimens of silver ore collected from the Echo Bay Mine (near Port Radium), Great Bear Lake, Canada³. Ore samples from this vein-type uranium deposit included two pieces of massive native silver mined from uraninite-rich areas of the 302 Stope, and a third sample from an occurrence of pitchblende, 206A W Drift in the mine, containing veinlets of native silver. The first two samples were counted directly but in the latter case the silver was separated from the ore by dissolution in nitric acid. The silver was therefore in intimate contact with the pitchblende until a few hours before it was counted.

For counting, a 70 cm³ Ge(Li) γ -ray detector and multichannel analyser were used. The sensitivity was 10 nCi, the same as that of the NaI(Tl) detector used by the Dutch workers. Since we did not possess an anticoincidence array, we were compelled to count for several days in order to achieve this. In all three cases there was no measurable ^{108m}Ag or ^{110m}Ag in the samples. On the basis of the Dutch work, we would have expected to have detected as much as 3 μ Ci.

We conclude that, at least for our samples, uranium does not produce significant activity in the silver associated with it. In view of the calculated low neutron flux², this is not surprising. Our conclusion can probably be applied to similar ore bodies.

R. W. Boyle (personal communication) cannot find any reported nuclear detonations which correlate with the time of origin of the activity as calculated by the Dutch workers. We agree with their current view (personal communication) that the most likely source of the reported activity is the addition of silver tracer to the silver during some stage of the refining process.

Yours faithfully,

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Great Glen Fault

SIR,—Detailed mapping of the regional metamorphic pattern of the central and northern Highlands has led to the conclusion that a post-metamorphic sinistral shift of 160 km must have occurred along the Great Glen Fault¹. A reappraisal of the considered data suggests, however, that the proposed shift probably represents a minimum estimate; a displacement of 200 km would, for example, fit the data equally well but even this figure cannot be taken as a reasonable upper limit of possible strike-slip movement.

The most likely northward continuation of the Great Glen Fault is through the Walls Boundary Fault in Shetland². This provides a slight curvature in the fault line which seems to have an important geophysical bearing on the displacement problem. Thus, it can be shown^{3,4} that a certain discordance in Devonian palaeomagnetism across the Great Glen Fault can be fully explained by incorporating a late or post-Devonian sinistral shift of at least about 200 km. At present, palaeomagnetic results cannot be used to set an upper limit of the actual movement but a displacement of at least 250 km is possible. What is really important at this stage, however, is to stress that a geophysical and a geological method have both led to practically identical palaeogeographic reconstruction of Scotland, which involve a transcurrent movement, at least twice as large as previously suspected along the Great Glen Fault. Consideration of the

lower age limit of this movement (provided by palaeomagnetic results) seems to indicate that the Strontian and Foyers granites (K/Ar ages of around 400 Myr, ref. 5) never formed part of the same intrusive complex.

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DR WINCHESTER replies: Storetvedt's comments are very welcome. The suggested displacement of 160 km was chosen as the optimum fit of the metamorphic patterns in the opposing blocks. A precise metamorphic zonal correlation across the fault is not possible because on opposite sides of the fault, Moinian rocks are concealed beneath Devonian sediments east of Inverness, and beneath Tertiary volcanics in Mull. The zonal pattern may therefore be extrapolated across these areas to fit a post-metamorphic displacement of between 140 and 200 km along the Great Glen Fault, before it becomes impossible to match without requiring an unjustified warping of the metamorphic pattern adjacent to the fault. A displacement of 250 km is therefore not supported by the metamorphic evidence. It is significant, however, that the maximum displacement allowed by the metamorphic pattern, and the minimum shift indicated by Storetvedt's palaeomagnetic work should agree so well.

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McCollough colour after effect

SIR,—McCollough¹ demonstrated a striking, long lasting colour after effect. Observers adapted (2–4 min) to a vertical grating of black and orange stripes alternating with a horizontal grating of black and blue stripes. Thereafter a pattern made up of a black and white vertical grating and an adjacent horizontal grating appeared tinted with colours complementary to the adapting colours. The

vertical grating appeared blue-green and the horizontal grating appeared orange.

Piggins and Leppmann² repeated the McCollough-type experiment with the adapting pattern stabilised on the retina by the conventional contact lens method. They were unable to build up the after effect with a stabilised image. They concluded that the eye must scan the adapting pattern to generate the after effect, and explanations of the after effect must include 'image motion mechanisms'.

Our experiments show that the after effect requires no retinal image motion. Four observers adapted to a high contrast sine-wave grating of two cycles per degree flashed on an oscilloscope field that was 12° in diameter. The observer carefully fixated a tiny light in the centre of the field and then pressed a button which presented a stationary grating for one 9 ms sweep. The luminance of the P4 white phosphor, as measured with a 1P22 phototube, fell to 1/e of the peak value in 1 ms. The field was dark between flashes. The grating was presented in a different, random position on each flash and could be vertical or horizontal. When vertical, it was viewed through a Wratten 30 magenta filter (or a Wratten 11 yellow-green filter) and when horizontal, through the yellow-green filter (or magenta filter). The mean luminance of the gratings through the filter was about 4 cd m⁻². The observer presented himself with a grating about every second for a total of 2,000 times. Every 50 flashes, the grating changed orientation and colour. After effects were built up to counter any initial colour bias that the observer reported while viewing black and white test gratings before adaptation.

All observers saw weak McCollough after effects of pink and green on a test pattern consisting of adjacent vertical and horizontal square-wave gratings of two cycles per degree. The pattern was viewed in fluorescent room light. The colours were more pronounced when the mean luminance was reduced considerably—from 100 to 0.1 cd m⁻².

Retinal image motion during adaptation cannot be completely ruled out in this experiment. It has been shown,³ however, that movements greater than 1 min of arc are very unlikely during attempted fixation of a target which is exposed for less than 20 ms, and the retinal image is virtually stationary for exposures less than 10 ms. The second experiment eliminates even these tiny retinal image movements.

High contrast vertical and horizontal square-wave gratings of two cycles per degree were placed on a diffusing screen to form two fields 9° in diameter.

These patterns were illuminated from the rear by Grass photo-stimulators rated at about 10⁶ candles. Measurements showed that the flash lasted less than 60 μs. The lights did not appear bright, and the after image they produced lasted 1 or 2 s. Four observers viewed the vertical grating through the magenta filter and the horizontal grating through the yellow-green filter. To spread the adaptation evenly over the retina, four tiny lighted fixation points were placed on each grating, separated by phase angles of 90° with respect to the fundamental period of each grating. The observer triggered the flash about every 2 s while fixating one of these lights. Each fixation light was fixated equally often. Total adaptation was 200 flashes, with alternation between the vertical and horizontal grating every 20 flashes.

All observers reported seeing the McCollough effect, which was very evident. The colours were still seen 30 min after adaptation. This experiment shows that no retinal image motion is required to build up the McCollough effect. Our method of stabilising the image has the advantage over the contact lens method in that the image does not fade over time, and is thus a potent stimulus.

Retinal image motion is thus not required for the McCollough effect. Flashed gratings and gratings stabilised by the contact lens method might well cause movement mechanisms to fire and thus adapt. But the optimal stimulus for these mechanisms is a pattern moving in a specific direction. Thus, these experiments tell us nothing about movement mechanisms. It is possible, however, to generate McCollough effects selective to the direction of motion^{4,5}.

We thank Professor Karl Pribram and Professor Leo Ganz for support.

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Mouse granulocyte precursors and multiple sclerosis

SIR,—Brown and Gajdusek¹ have recently reported failure to reproduce the suppression of peripheral blood granulocytes which was described² in mice following inoculation of material from patients with multiple sclerosis (MS).

We have also studied the effect on groups of ten weaning C57BL and CBA mice of intraperitoneal inoculation of 0.2 ml serum or brain extract (prepared as in ref. 2) from patients with MS. In agreement with Brown and Gajdusek, we found no differences in peripheral blood granulocyte levels up to 35 d after inoculation between mice inoculated with MS material, normal human serum, normal human brain or saline.

We used the agar culture technique for granulocyte-macrophage colonies³ to enumerate granulocyte-macrophage precursor cells (colony-forming cells, CFC) in the marrow and spleen of inoculated mice, and in addition measured serum levels of the myelopoietic colony-stimulating (CS) factor⁴. Table 1 shows that 34 d after inoculation of MS brain extract into groups of 5 weanling C57BL mice there was no depression of granulopoietic potential compared with similar mice given normal brain extract or the medium used to prepare the extracts.

Table 1 Colony-forming cells after inoculation of normal and MS brain.

Material inoculated	CFC per femur (× 10 ⁻³)	CFC per 10 ⁶ spleen leukocytes	Serum CS activity
Medium	42 ± 17	25 ± 15	10 ± 7
Normal brain	45 ± 10	19 ± 8	8 ± 5
MS brain	61 ± 6	16 ± 7	15 ± 7

In this experiment the mice inoculated with MS brain actually showed a statistically significant increase in CFC per femur (but not in spleen which is usually a more sensitive indicator of changes in CFC populations⁵) compared with the mice given normal brain (0.01 > P > 0.005). No consistent differences in any of these parameters were found, however, between MS serum-inoculated mice and controls when tested in both C57BL and CBA strains.

We thank Dr J. H. D. Millar for sera from his MS patients, Dr Margaret Haire for specimens of normal and MS brain and the Medical Research Council for financial support.

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book reviews

General relativity

Gravitation. By C. W. Misner, K. S. Thorne, and J. A. Wheeler. Pp. xxvi+1279. (Freeman: San Francisco and Reading, December 1973.) £19.20 boards; £8.60 paper.

In most cases it is probable that, if a scientific discovery had not been made by the person normally credited with it, it would have been made by someone else within a few years. There is one notable exception to this general rule: had Einstein died before 1916, the world would have probably had to wait another 50 years or so for the General Theory of Relativity. In fact Einstein was ahead of his time: after an initial burst of activity in the 1920s, there was very little work on the theory until about 1960. This neglect was caused partly by the belief that the theory was too complicated to allow predictions to be made in any but the simplest cases and partly by the fact that there did not seem any prospect of comparing the predictions with observation apart from the three famous Solar System tests which Einstein himself proposed.

During the period 1920–1960 the most exciting field of physics seemed to be quantum theory. The success of quantum electrodynamics led most physicists to feel that physics was Feynman diagrams. They distrusted general relativity because of its classical and geometric nature. This dislike of geometry is shown, for example, by the particle physicist Steven Weinberg in the introduction to his otherwise excellent book *Gravitation and Cosmology* (John Wiley, New York, 1972): "... too great an emphasis on geometry can only obscure the deep connections between gravitation and the rest of physics. . . . I believe that the geometrical approach has driven a wedge between general relativity and the theory of elementary particles".

But geometric insights have played an important part in many of the outstanding recent theoretical developments such as black holes, space-time singularities and gravitational radiation. The answer therefore seems to be not to free general relativity from geometry but to teach geometry to physicists brought up on the normal ideas of special relativity; that is, to teach them to regard space-time as a differentiable manifold and not as a flat vector space.

This is what Misner, Thorne and

Wheeler have set out to do in their book. They have also endeavoured to give at least an introduction to those fields such as cosmology, gravitational waves, post-Newtonian effects in the Solar System, relativistic stars and black holes where general relativity is now, or is on the point of, making contact with the recent great advances in observation. All this combined with fairly large print and wide margins has produced a book weighing 6 pounds. Because this is too long for most postgraduate courses on general relativity, the authors have divided the material into two tracks which are indicated on the top corners of the pages. Track 1, which is designed to accompany a one-semester course, gives an impressionistic overview of the theory and its applications but to perform any calculation one would really need to master most of the Track 2 sections on the basic theory.

The style is typical of the Princeton school (Misner and Thorne are former students of Wheeler at Princeton). It is aimed more at giving the reader an intuitive feeling for the concepts involved than giving a mathematically rigorous axiomatic account. Important results and other material of interest are displayed in boxes. These are generally helpful though they sometimes rather interrupt the text. The book is also well provided with exercises ranging from easy to major research problems. These should be very helpful to students learning the subject.

The authors' research interests have obviously influenced the coverage of the book. There are very good sections on relativistic stars, black holes and experimental tests of relativity. On the other hand the section on cosmology is less detailed than that in Weinberg's book and suffers from the ideological insistence that the Universe is spatially closed. The section on gravitational waves gives a good account of the generation and detection of gravitational radiation but does not mention the work of Bondi, Sachs, Newman and Penrose on the 'peeling off' of the curvature tensor, the Bondi mass loss formula and the Bondi–Metzner–Sachs group. These and the comparative neglect of spinors are the main gaps in this book, which does not aim to describe in detail global results such as singularity theorems. Despite these omissions the book is a major landmark in the field and is likely to become the most widely used textbook

and reference work on the subject. It is well printed and bound and the paperback version is cheap for a book of this size.

S. W. HAWKING

Radial parameters

Ligand-field Parameters. By M. Gerloch and R. C. Slade. Pp. xii+235. (Cambridge University: London, August 1973.) £5; \$15.

ALTHOUGH many books exist dealing with the theory of transition-metal complexes, this one is welcome, since it treats the subject in a novel way. Other texts approach ligand-field theory through symmetry and group theory, being concerned with aspects of the subject determined by molecular symmetry alone. This is a valid approach, but it is sometimes necessary to stress those parts of ligand-field theory where the molecular symmetry is less significant, and this is done here.

For all systems, group theory can only give information on quantities dependent upon the angular properties of wave functions. Radial properties appear only as proportionality constants. Furthermore, complexes of lower than cubic symmetry are less amenable to group-theoretical treatment, needing large numbers of parameters to describe the system.

In this book stress is laid on calculations of radial properties of regular octahedral and tetrahedral complexes, and the ligand-field parameters of non-cubic systems, thus rationalising pertinent data on such complexes. A summary of the role of symmetry in ligand-field theory is followed by a development of the crystal-field formalism, with a discussion of inter-electron repulsion parameters in cubic systems. Treatment of the radial parameters in various complexes of lower symmetry follows, with emphasis on trends in the parameters C_p and D_q .

The second half of the book seeks to interpret these radial parameters, covering calculations of $10Dq$, and use of the point charge model and semi-empirical molecular orbital methods (especially the angular overlap model) in rationalising trends in Dq and C_p . The final chapter contains a discussion of the Nephelauxetic effect.

The authors hope that the book will be useful to advanced undergraduates and young researchers; but although the treatment is sound and logical, the level of difficulty will probably prove to be too great for all save very few

undergraduates. Nevertheless, this is a very worthwhile contribution to a little-known aspect of an important area of chemical theory, which should be read by anyone with a serious interest in ligand-field theory. The book is well produced, with extremely few typographical errors.

G. DAVIDSON

Bioengineer's dreams

Phloem Translocation. By M. J. Canny. Pp. x+301. (Cambridge University: London, November 1973.) £7.50; \$22.50.

THE question of how cells in phloem tissue transport organic foodstuffs, viruses and other material from one end of a plant to the other, remains, tantalisingly, open. The nature of the movement and the force which drives it are still unknown. It is not even agreed about where in the pipelines any forces might be applied.

The reasons for this ripe state of affairs, and suggestions for improving it, are set out in this lively book by Martin J. Canny, Professor of Botany at Monash University.

It is now ten years since Professor Canny first proposed his own hypothesis or model to explain translocation. In the very first sentence of the preface he warns "This book is less a review of a field of plant physiology than a lengthy statement of a point of view about that field which, in the course of the argument involves the review of most of the work". His point of view is that translocation behaves like diffusion but is faster.

The angle of view in part one of the book ("The Experimental Facts", 211 pages) is wide. It gives an interesting, though sometimes closely argued account of the ups and downs of research into translocation; of the quantities translocated; of how the channel of movement was identified; of how patterns and rates of movement and gradients of concentration were studied; of the effects of temperature; of the nature of phloem exudates; of why functioning sieve elements are so difficult to examine and experiment with; and of what is known or controversial about their structure. In particular Professor Canny discusses very fully how the distribution of radioisotopic tracers and their concentration profiles in the transport channels are related to various patterns of flow proposed to occur through sieve tubes.

Part two (52 pages) is divided from part one by a group of 23 plates which contains 45 micrographs and photographs and two line drawings. These are well chosen to illustrate the text and beautifully reproduced.

In part two ("Towards a Mechanism") Professor Canny outlines briefly various mechanisms which have been

proposed to explain translocation, and discusses their drawbacks. He then describes his own model as he first based it, in 1962, on hypothetical membranes round transcellular strands proposed by Dr R. Thaine. But he goes on to say that "The prime objection to the model is that the strand structures it uses seem not in fact to be there, nor any such tonoplast-type membranes as were originally imagined as separating them from the sap". Filaments, perhaps gathered together in bundles are all that appear in the electron microscope to warrant his highly sophisticated calculations, which have been criticised^{1,2}. He now seems to suggest that "accelerated diffusion" might be caused by flow within (and of?) 250Å diameter tubular filaments, or within "small aggregates of them", and driven by "mechanicochemical means". I find flow through such filaments hard to believe; their resistance would surely be enormous³. Far-fetched models have an irritant value which provides much of the spark for research into translocation. But they can become an entanglement.

There are numerous useful tables, graphs, and drawings in the text. These provide essential information from many different sources for those who wish to make their own calculations about translocation, or try their hand at model building. The book has author and subject indexes, and a bibliography with more than 330 references. There are four short appendices.

I found this a stimulating and thought-provoking book. It should be read by anyone who wishes to know more about translocation. It demonstrates vividly how enthusiastic speculation stimulates the search for hard facts.

RICHARD JOHNSON

¹ MacRobbie, E. A. C., *Biol. Rev.*, **46**, 429-481 (1971).

² Crafts, A. S., and Crisp, C. E., *Phloem Transport in Plants*, 277 (Freeman, San Francisco, 1971).

³ Weatherley, P., *Physiol. Vég.*, **10**(4), 731-742 (1972).

Bacterial envelopes

Bacterial Membranes and Walls. Edited by Loretta Leive. Pp. xv+495. (Microbiology Series.) (Dekker: New York, December 1973.) \$38.

It is fashionable in some quarters to pretend that the prokaryotes are a spent force as research models in biology. This collection of essays, all written by distinguished experts, might be read with great profit by those who promulgate or accept such views. Chapters such as those by Mindich on membranes, by Kaback on transport, by Luria on the colicins, by Tomasz on

the uptake of DNA, by Pardee, Wu and Zusman on bacterial division and, despite its specialised title, certainly that by Ghuyssen and Shockman on the biosynthesis of peptidoglycan (mucopolysaccharide, murein) all embody principles of general biological importance. In particular the necessary confluence of those interested in DNA replication and nuclear segregation with those interested in cell envelopes, to tackle the fundamental biological problem of cell division, is illuminating.

Although the subject of cell division is mentioned in the title of only one chapter, five out of the total of nine essays deal at lesser or greater length with it. Indeed, it might have been profitable to put together a separate section of the book on this subject, taking and expanding the relevant sections from some of the other chapters. For example, the part of Ghuyssen and Shockman's article called "Relationship to Morphogenesis and Division" could well have stood on its own in such a section. This section would also have included the stimulating but maverick article by Henning and Schwarz which points its didactic finger in almost the opposite direction to several of the other chapters, as well as the thoughtful and cautious article of Pardee with its epilogue. This is not to criticise either the book or the editor who has persuaded her distinguished soloists to perform with such crystal clarity of tone, even though she did not integrate them into a consonant orchestra, had this been desirable. It is rather meant to emphasise unsatisfied intellectual hunger stimulated from the brief remarks often made almost as asides by some of the authors.

The generality of the title is a little misleading since some considerable lacunae exist. There are, for example, no serious considerations of energy metabolism, despite the siting of important parts of the electron transport chain in membranes, no general or detailed ultrastructural studies, no biophysical studies, nothing on the export of macromolecules other than DNA, and no serious study of the transport of ions. The latter might have allowed the supporters of the chemiosmotic hypothesis a fair chance to reply to Dr Kaback's strictures on them. A brief mention of the L-forms of Gram-positive bacteria such as *B. subtilis* or *Streptococcus haemolyticus* might have given pause for thought to Henning and Schwarz in their considerations of the determinants of cell shape for, to adopt their style—if membrane, not mucopolysaccharide formation, is alone shape determining how is it that unstable L-forms of Gram-positive bacteria totally without regular shape or division and without mucopolysaccharide

rapidly revert to normally shaped bacteria which divide regularly when penicillin, a quite specific inhibitor of one step in mucopeptide biosynthesis is removed from their growth medium? But this book is already nearly 500 pages long and refers to some 1,400 papers.

References in the main text extend to 1972 and a short appendix at the end of the book improves this to 1973 for some chapters; considering the publication date of 1973 this is very satisfactory. It is beautifully produced, well indexed and singularly free of typographical errors. Both the editor and the publishers are to be congratulated. I hope that Dr Leive may be persuaded to edit a second companion volume in this microbiology series that will deal with the subjects perforce omitted from the present one. The book is to be recommended to all those directly interested in cell surfaces. Individual chapters could be suggested as supplementary reading to postgraduate and final year undergraduate students in biochemistry or microbiology, but the perusal of some more general books on bacteria and bacterial walls and membranes would be a necessary preliminary.

HOWARD J. ROGERS

Taxonomy of ferns

The Phylogeny and Classification of the Ferns. Edited by A. C. Jermy, J. A. Crabbe and B. A. Thomas. Pp. xiv + 284. (Supplement No. 1 to the Botanical Journal of the Linnean Society, Vol. 67.) (Academic: New York and London, December 1973.) £9; \$25.

THIS is a collection of papers based on those presented at a joint symposium held in 1972 by the Linnean Society and the British Pteridological Society. The original programme has been expanded by the addition of three further papers, extensive reference lists and, judging by the concentrated factual content of some papers, additional detailed data. New approaches and techniques of the last 20 years have revealed errors and inadequacies of past taxonomic treatments without firmly establishing alternative classifications. In several of these papers the view is expressed that conclusions are tentative and await further critical investigations. It was the organisers' stated intention therefore that the symposium should provide an opportunity to take stock of the present situation and provide stimulus and direction for further work. In this they will have at least partially succeeded, by inviting leading researchers to give authoritative and up-to-date assessments in their own area of interest. Supported by detailed data and extensive bibliographies these add up



Fiddle-head of soft shield-fern *Polystichum setiferum*.

to a useful reference book for the specialist pteridologist.

But by basing the programme on the choice of speakers rather than on themes within the overall broad scope of the title, the programme lacks cohesion, and few of the papers are linked together in any way. As, furthermore, there is no record of any discussion which may have been stimulated by the papers, the reader is left with the impression that the unique feature of a symposium has been lost.

On the dust jacket, there are the further claims that this is "a reference book to the cytology, anatomy, palynology, chemistry and gametophyte studies of the Filicopsida" and, making a curious distinction, "a valuable purchase for many botanists and plant physiologists". These claims, perhaps those of the publisher rather than the editors, are misleading. The cytology is largely restricted to chromosome numbers, the anatomy and palynology occurs mostly as scattered references in papers on particular genera or families, and the gametophyte study takes no account of the effects of environmental conditions on the development of diagnostic characters, even though protonema and prothallus development is known to be particularly sensitive to such factors as temperature, light intensity and light quality. Several of the diagnostic characters discussed in Atkinson's paper on the gametophyte as an indicator of family relationships can be induced or suppressed at will in, for example, *Dryopteris* species merely by changing the cultural con-

ditions. Botanists (and plant physiologists!) not already familiar with the ferns will find the several essentially traditional treatments of groups such as the dennstaedtoideae, cheilantheae, Oleandraceae, Thelypteraceae, Polypodiaceae and Aspidiaceae of limited value. Several areas of more general interest such as serological and numerical taxonomy, breeding systems and apomixis, developmental physiology and the ecological significance of phylogenetic changes are omitted and the biosystematic approach is restricted to one paper by Lovis on the Aspleniaceae. Professor Manton comments that the production of phyletic schemes for the Filicopsida involves every discipline in botany, but this is not fully reflected in this book.

Those with historical interests will enjoy tracing fern classification systems back to the time when it was commonly believed that fern spores collected on Midsummer's Eve and placed in the shoe rendered the wearer invisible (see Shakespeare, W., *Henry IV Part 1*, act 2, scene 1, line 96 (1576)). Also, botanists with any interest in taxonomy will find some of the more general papers worth reading, particularly those by Swain *et al.* on the possibilities for biochemical systematics in ferns, by Van Cotthem on the classification of stomatal types, by Lovis on the biosystematic approach in the Aspleniaceae and by Wagner on future challenges in fern systematics. Walker's comprehensive survey of fern chromosome numbers and Wood's and the Tryons' use of spore surface structure revealed by scanning electron microscopy may also be of some use to those working with other groups of plants.

The limited success of this volume in achieving its secondary aims only emphasises the need for a general text on the biology of ferns to interest students in these fascinating plants and to re-educate those botanists whose impressions of the Pteridophytes are based on their past experience of unimaginative teaching within a narrowly systematic context.

A. F. DYER

Petrol and polar bears

Man, Nature and Ecology. By Keith Reid, J. A. Lauwerys, Joyce Joffe and Anthony Tucker. Pp. 418. (Aldus, Jupiter: London, March 1974.) £3.95.

THIS large and lavishly illustrated book aims to give a background in ecology to the layman with an interest in doom. It is too diffuse to have a profound impact—the four authors cover ecology, anthropology, rare animals, and problems of population and resources. The layman who remembers his school biology and reads the newspapers will know much of it already.

The parts I found most interesting were those on the problems inherent in the use of pesticides, antibiotics and the products of the green revolution.

The book ends with a list of suggestions for an ecologically virtuous life. Ironically one of the recommendations is to save paper by using both sides when writing letters: the authors don't mention how many trees had to be felled to produce their book.

GILLIAN MOORE

Classify knowledge

The Fabric of Knowledge: A Study of the Relations Between Ideas. By J. L. Jolley. Pp. 130. Duckworth: London, October 1973.) £2.95.

THIS monograph will be of interest to anyone concerned with the problems of organising scientific or technical documents. It is more specialised than the title suggests, being an examination of the use of integrative level theory for the organisation of concepts in scientific and technical subjects. There are three parts. The first recounts the development of Mr Jolley's ideas, the second supports them by means of set theory and the third is a brief summary of previous ideas applied in the organisation of knowledge.

The first section is the most satisfactory and least controversial. It should be read in conjunction with the account of similar work by the Classification Research Group in *Classification for a General Index Language*, by D. J. Foskett (Library Association, 1970). Despite the common starting point there seem to be considerable differences of detail in the two sets of ideas. The levels identified are not exactly the same and their method of use varies: the CRG uses them for organising entity concepts only, whereas Mr Jolley includes all concepts. His semantic types used within the levels also differ from the categories used by the CRG. Unfortunately a full comparison is not possible since Mr Jolley has not written at sufficient length to do himself justice. A lot more examples would have helped to clarify the sometimes eccentric terminology and definitions that in themselves are inadequate for complete understanding.

There is no reason to doubt the usefulness of Mr Jolley's analysis, since it is based on many years of work in indexing consultancy. Even the set theory may be useful, but the exposition here is difficult to understand. Whether it is really necessary is another matter: the CRG have managed without it. It could be that they have merely failed to make explicit the real theory underlying their work, but the experience with categories should be a warning against Mr Jolley's claim

to objectivity. There are no generally accepted categories of reality, and their use in classification can only be judged pragmatically. The only way to be objective in the classification of ideas is to examine the nature of knowledge rather than the nature of some supposed objective reality.

There seems little ground for Mr Jolley's optimism about the extension of his theory beyond science and technology. Integrative level theory relates to natural objects and there is no obvious reason why it should provide a structure for philosophy, history, religion or the arts. It is sufficient that it has a use in science and Mr Jolley's work is welcome independent support for that of the CRG. Both his suggested pattern of ideas and the use of set theory are worthy of further research.

D. W. LANGRIDGE

Analysis

Elementary Real and Complex Analysis. By Georgi E. Shilov. Revised English edition translated and edited by Richard A. Silverman. Pp. xi+516. (Mathematical Analysis: Vol. 1). (MIT: Cambridge, Mass. and London, 1973.) \$14.95.

THIS translation, by R. A. Silverman is, as usual, of high standard. The appearance of the book is good, the printing and accuracy so meticulous, that an error on page 223, where $f(x_0) + h$ should read $f(x_0 + h)$, comes as a shock.

The book covers much of the analytical knowledge demanded of a mathematics graduate—real and complex numbers, vector functions, metric spaces, limits, convergence, elementary functions, the theorems of the calculus, Riemann (–Stieltjes) integrals, analytical function theory (for piecewise smooth curves) and improper integrals. The chapters on limits (using directions) and improper integrals are probably the most refreshing. Functions of several variables, measure and Lebesgue integration receive only passing reference.

The author's declared aim is an easier 'Dieudonné'; nevertheless mathematical sophistication, and hard thought about abstract ideas, are demanded of the reader particularly in the earlier chapters. This may prove a deterrent to weaker students, scientists and engineers for whom the book is also intended. There is a good collection of examples, some normally accorded theorem status, some difficult even with the hints of the appendix.

This is a scholarly book; carefully used it could provide a logical, integrated and economic presentation of basic work.

MARGARET JACKSON

Domestic life in Africa

Man and Woman among the Azande. Edited by E. E. Evans-Pritchard. Pp. 197. 8 plates. (Faber: London, February 1974.) £4.50.

SIR EDWARD EVANS-PRITCHARD died towards the end of 1973, and this is the last book to come from his pen. As such it is appropriate that in it he returns to the study of the Azande people of Central Africa, the group about whom he first wrote more than forty years ago and about whose thought he published his first major work.

This book is a collection of Zande texts, some taken down in the 1920s, some written more recently. Evans-Pritchard links these with brief comments of his own, and in a few places discusses and clarifies obscure passages. He is always careful to allow his Azande informants to speak for themselves and his editorial presence never prevents his reader from having to deal for himself with the complexities, contradictions and individualities of Zande thought and belief.

Evans-Pritchard was a great and respected social anthropologist, and it is probably due to his eminence that he was able to publish this book, for it is hard to believe that a commercial publisher would risk issuing a series of native observations about the problems and joys of domestic life if these were not supported by the name of such a famous author. But we must be thankful for that eminence, for it has made available a series of fascinating documents about the relations of men and women in a single exotic culture. Material such as this has rarely been published in book form before.

One of the main qualities of this book is that it shows the almost-raw material from which anthropologists build up their analyses and abstractions. Women quarrel, men complain, an informant recalls a story heard about a neighbour, an old man criticises the conduct of the young. All this is faithfully and simply recorded here and it is left to the reader to make what he can of it. In some places he would clearly benefit from additional information or guidance from the editor, but this is not provided. To get the full worth of the book it is therefore necessary to read some of Evans-Pritchard's other writings on the Azande; once this is done the mass of data about male/female relations can be used more profitably.

In the final count anthropologists depend on the quality of their informants. Evans-Pritchard, like Malinowski and others before him, always stressed the need to record information *verbatim*; only in that way, he argued, could a true appreciation of native

ideas be developed. Although the texts published here are but a small proportion of those collected during his working life, they reveal his skill at eliciting information and also his tact and sensitivity in allowing people to say or write what they wanted and not what would have best suited him. Rejecting analysis in his final works, he concentrated on making known the views of those he studied; the present book is typical of this approach. Though one might wish for more of his own views and ideas, the work as a whole provides a mass of interesting and valuable data. It is also a tribute to Evans-Pritchard's lifelong fascination with the lives and ideas of other men and his deep respect for these in all their variety.

M. D. McLEOD

Molecular sieves

Zeolite Molecular Sieves: Structure, Chemistry and Use. By Donald W. Breck. Pp. ix+771. (Wiley: New York and London, January 1974.) £18.

THERE have been several shorter monographs on particular aspects of zeolite chemistry and technology, mostly in Russian, and also several bibliographies. In 1968, 1971 and 1973 volumes have appeared embodying the papers read in three international symposia on molecular sieve zeolites. But Dr Breck's monograph is the first comprehensive text reviewing all aspects of zeolites except their catalytic properties. A second monograph is being considered which will cover this important area. I hope this will be completed in due course in the same comprehensive pattern.

In the book under review the introductory chapter is followed by chapters on structure, mineral zeolites, synthetic zeolites, physical properties, chemical properties and reactions, ion exchange, adsorption and finally manufacture and properties of commercial sieve zeolites. A feature of the book is the amount of illustrative material presented as tables. In the field of molecular sieves progress in the basic science and in applications is rapid and the incorporation of the most recent developments presents considerable problems. The author has nevertheless been successful in providing coverage up to about 1972. The discussions of zeolite structure, crystal chemistry, synthesis, chemical reactions and properties are particularly interesting.

One may ask whether Dr Breck's classification of zeolites will appeal to mineralogists since it produces some strange bedfellows, for example analcime, phillipsite, paulingite and yugawaralite are all given as members of the same group. Cages of linked tetrahedra of $(\text{Si}, \text{Al})\text{O}_4$ are referred

to as α -, β -, γ -... cages. In my opinion these cavities would be better designated as 14-hedra, 26-hedra, and so on since this conveys partial information about their nature. The chapters on adsorption and ion exchange reproduce many isotherms, although usually without the experimental points which allow one to assess the accuracy and reversibility achieved in the original researches. In the introductory chapter a brief review is given of several other materials having molecular sieve properties such as Saran charcoals and alkali metal graphites, but one of the more important types, the alkylammonium-exchanged clay minerals, receives virtually no attention.

There are various printing errors but they do not usually result in ambiguity and are small matters in a book of this compass. The author is to be congratulated on completing a monograph which will, despite its price, be indispensable to all those interested in molecular sieve science and technology, and which should become the first standard work on this subject. The format is attractive, clear and easy to read.

R. M. BARRER

Plant components

Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis. By J. B. Harborne. Pp. x+278. (Chapman and Hall: London; Halsted Press, a division of Wiley: New York, 1973.) £4.80.

THE aim of the author is to provide undergraduate students and research workers with a series of proven methods of phytochemical analysis in a single volume at a reasonable cost. After a brief survey of general extraction, analytical and identification procedures, specific methods for each major class of organic constituent found in plants are considered. Much of the book (98 pages) is concerned with a comprehensive discourse of methods used for the analysis of phenolic compounds and terpenoids. The coverage of the organic acids, lipids and related compounds, nitrogen compounds and sugars, though not as extensive as the phenolics, is adequate. The macromolecules including the nucleic acids, proteins and polysaccharides are deliberately considered in less detail owing to space limitations and widespread coverage in other texts. It is unfortunate that more space could not have been allocated to this important area of research.

Each chapter contains sections on the chemistry, distribution and recommended qualitative and quantitative procedures for each component which have widespread application in

research laboratories. Sufficient detail has been included to enable the inexperienced worker to attempt the methods and the practical experiments in each section should help the student gain experience with the procedures. The carefully selected references at the end of each section should aid the worker to quickly develop or modify the techniques to suit his own requirements. The author assimilates the rapidly expanding and difficult area of phytochemical methods into a well written and informative text which should be welcomed by both students and researchers.

G. NORTON

Flies and humans

Flies and Disease. Vol 2: Biology and Disease Transmission. Bernard Greenberg. Pp. x+447. (Princeton University, Princeton, September 1973.) £4.50.

THIS second volume of *Flies and Disease* complements volume 1 which appeared in 1971.

The introductory chapter provides an historical survey of the association of flies with man throughout recorded history. This is one of the most fascinating chapters in the book, documenting both early myths and observations on the natural history of flies. A slip of paper in the mouth of a mummy "The maggots will not turn to flies within you" illustrates the Egyptians' appreciation of insect metamorphosis many centuries ago.

The second chapter deals with the life history and habits of ten common genera of synanthropic flies. There are several important omissions here (for instance, *Musca domestica*), justified on the grounds of treatment elsewhere in the literature, and the information given is occasionally rather disjointed because of the variety of interests of the original authors. The chapter ends with a discussion of the estimation of fly density (simple Lincoln index only) and dispersal: table 3 is a useful summary of the dispersal of more than 40 fly species.

Chapter 3 investigates flies as hosts of a variety of micro-organisms and describes the changes which take place in the gut fauna during metamorphosis. Many larval microbes are lost during pupation and emerging adults may even be sterile. The relevance of this to the vectorial capacity of saprophagous flies is examined.

The two final chapters discuss flies as disseminators of more than 50 human and animal diseases. In the absence of definitive parasite stages in the insect hosts, the importance of flies relative to other transmission pathways is often based on circumstantial evidence alone; for example a correlation of increased numbers of

disease cases with seasonal plagues of flies. Professor Greenberg deals with these examples in an open-minded way, admitting where the evidence is slight and emphasising where new research efforts should be directed.

The book has an extensive bibliography, including many early works. The style of the illustrations is very variable and occasionally disappointing, but the volume as a whole will be a useful source of information and reference for public health workers, epidemiologists and entomologists alike.

DAVID ROGERS

Image of a scientist

Science as a Career Choice: Theoretical and Empirical Studies. Edited by Bernice T. Eiduson and Linda Beckman. Pp. xv+735. (Russell Sage Foundation: New York, 1973.) £10.40.

WHY I feel able to embark upon the formidable task of reviewing this work, which is a vast book largely concerned with psychological theory and studies of the process of socialisation, is that the choice of career is a crucial factor in economic analysis of the way in which the labour market works. It is therefore necessary to review as much of the evidence as possible presented by a variety of disciplines in order to see what it is that drives people to make one choice rather than another.

This interesting study is a collection of papers concerned with the mechanisms of career choice and the way that people drift into the physical and other sciences, and what sort of people they are. Scientists apparently (page 670)

"lead quite, unpretentious, even-tenored, rather steady lives. They come home regularly for dinner, and spend the time before and after dinner with their children and wives; pursue their hobbies systematically; and more often than not, spend the evenings reading journals, novels, magazines, or watching television. Most live on a fairly modest scale and do not spend much for theatres or entertainment... despite the fact that their home lives are interesting and varied, one gets the impression that these do not reflect their most exciting selves. For one thing, the interviews reveal that the scientists are not able to give the most significant parts of themselves to home and family."

To an outsider, this is an extraordinarily perceptive description of the home lives of many scientists, and also suggests the degree of secretiveness and obsession with work which has seemed so often a characteristic of scientists with whom one has been thrown into contact. Terman seems to

have shown that scientists chose a subject early, and that their early socialisation tended to isolate them by making them feel different from other children. According to other studies, those people who are going to take up science develop an image of a scientist which tends to become self-confirming: the scientist is committed, studious, collaborative, concerned primarily with science; and that this perpetuation of a self-image which is assisted by highly developed social structures therefore tends to make the scientific community a fairly close one which is self-recruiting. This would also suggest that it was a social system which tended to push other people out, particularly people who developed an interest in science later in life, or people who had unusual social characteristics.

This description of the physical scientists contrasts markedly with those who call themselves social scientists. There seems to be some evidence that physical scientists come from individualistic and rather cold families (page 17) with high intellectual motivation. There is also, it seems, some evidence that the classic image of the pure scientific researcher clashes somewhat severely with most scientists' actual experience of their work. Interestingly enough, there are astonishingly few female or black scientists in the American studies which are cited here, and therefore the scientific community in the United States may be described as predominantly white and male, thus presumably reinforcing the tendencies towards a self-perpetuating community which have just been outlined.

The editors point out that the evidence, although very bulky, is in fact sketchy and derived from a great many partial studies of certain aspects of the problem, and therefore the very brief allusion which has been given here to some aspects of the work must be treated with great caution. Nevertheless, it does illustrate the probability that career choices between becoming a non-scientist or a scientist, and within the sciences, are largely affected by what economists would regard as irrational motivations, and also implies to the outsider that there must be a considerable number of people inside science who have been attracted into it by their own fantasies and who are now living in a world in which their fantasies clash rather sharply with reality. This may not be an untypical situation, but presumably it must be particularly disillusioning inside a closed profession like science, where so much of the original choice of career has depended upon high hopes and aspirations.

JOHN VAIZEY

Lymphocyte dogma

T and B Lymphocytes. By M. F. Greaves, J. J. T. Owen and M. C. Raff. Pp. vii+316. (Excerpta Medica: Amsterdam; American Elsevier: New York, 1973.) £14.08.

HERE is a book to fill with joy the hearts of cellular immunologists. So many pages devoted to T and B lymphocytes and only 4p per page.

T and B lymphocytes, by which is meant lymphocytes derived from the thymus and lymphocytes derived from the bursal equivalent (whatever that is) respectively, have after a shaky start in the 1960s become all the rage at the beginning of the 1970s. The present book represents a sort of consummation of this rage.

The history of the notion of two modalities of lymphocytes is given *pari passu* with a general account of the relationship between the immune response and the lymphoid system. The variously described properties of T and B lymphocytes are adequately documented. The authors go in detail into the mysteries of T and B lymphocyte participation in immunological responses and as a rousing finale consider the clinical applications of T and B lymphocyte theory. There is an appendix said to deal with the manipulation of T and B cell responses and an extensive and up-to-date reference list. The index could be more comprehensive but the diagrams and illustrations are good.

It seems on compelling evidence that the various chapters of the book have been written each by a different author but the blend overall is eminently readable and not markedly reiterative. Further, there are many and healthy instances in which ignorance in relation to particular points of fact is stressed. The book is heavily orientated towards work on mice but in this respect it reflects the activities of the bulk of contemporary cellular immunologists.

Greaves, Owen and Raff are to be congratulated on a timely and carefully prepared book which, despite its price, will be a boon to teachers of immunology. The only danger in it is that it will be seen as an orthodox statement of fact rather than what it is, the enunciation of a most interesting working hypothesis.

A. J. S. DAVIES

Erratum

In the illustration "Butterfly Collection" (248, 289; 1974) the habitats of *Idea hypermnestra* and *Marpesia chiron* should have been given as Malaysia and South America respectively.

obituary

N. A. Mackintosh

NEIL ALISON MACKINTOSH, CBE, DSc, ARCS, the distinguished biological oceanographer and authority on the ecology and populations of whales, died on April 9, at the age of 73. He was educated at Westminster School and Imperial College where he very soon showed an aptitude for zoological research; in less than two years after graduation he had completed two papers on such widely different subjects as the chondrocranium of fish (*Proc. zool. Soc.*, 1923) and the crystalline style of gastropods (*Q. Jl. microsc. Sci.*, 1925).

He was in at the very beginning of that great enterprise, the Discovery Investigations of the Antarctic seas, when in 1924 he led the advance party to establish and take charge of the Marine Laboratory for the study of whales at South Georgia. Later he took part in three major expeditions of the *Discovery II*, being leader of two circumpolar voyages and bringing back a wealth of information on the plankton and hydrography of the Southern Ocean. In 1936 he had succeeded Dr Stanley Kemp as Director of Research until 1949 when the Investigations were merged with the new National Institute of Oceanography, of which he became deputy director, and since 1936 he had edited the long series of '*Discovery Rep.*' to which he made many outstanding contributions including one to be published in the thirty-sixth volume only four months before he died. In 1961 he established and directed the Institute's whale research unit at the British Museum (Natural History). He took a prominent part in the International Whaling Commission, being chairman



of its Scientific Committee. His contributions to knowledge lay in two main fields: the biology and conservation of whales, and the oceanic macroplankton.

It was at the laboratory adjacent to the whaling station at Grytviken, South Georgia, and on visits to stations on the African coast during the Antarctic winters (when the whales go north) that Mackintosh and Dr J. F. G. Wheeler, working together, amassed the enormous amount of information, based on the examination of nearly 1,700 whales, for their important monograph on the Southern Blue and Fin whales (*'Discovery Rep.*, 1, 1929). This and a number of later reports by Mackintosh laid the foundations of most of the current knowledge of the economically important species.

At Grytviken, Mackintosh and

Wheeler discovered the remarkable rates of growth of the Blue and Fin whales. Mackintosh's book *The Stocks of Whales* (1965) is an important contribution to a study of their populations and conservation prospects based on a number of his earlier investigations, particularly his "Southern stocks of whalebone whales" in '*Discovery Rep.*, 22, 1942.

He made an extensive oceanographic survey of the macroplankton of the Atlantic sector of the Antarctic seas and was the discoverer of a remarkable seasonal vertical migration of many of the species whereby they are carried northwards in the surface waters during the summer months and then sink in winter to be returned towards the pole by a lower south-bound current ready to arise again the following spring. More recently, from the vast collections of earlier years, he renewed the investigation of the krill, producing two important studies: one relating the life cycle to ice and water conditions (*'Discovery Rep.*, 36, 1972) and another on the circumpolar distribution of the post-larval stages (*'Discovery Rep.*, 1973).

Neil Mackintosh was one of the kindest and most modest of men, intensely disliking anything in the way of publicity. Indeed, his retiring nature was perhaps a fault, for because of it, so few in the outside world realised the greatness of the Discovery Investigations' achievements, including, of course, his own. He was awarded the Polar Medal in 1942 and the Patron's Medal of the Royal Geographical Society in 1954.

Announcements

Appointments

Henryk M. Wisniewski has been appointed Director of the Medical Research Council's Demyelinating Diseases Unit at Newcastle upon Tyne.

Gwynne James Morgan has been appointed Professor of Theoretical Physics at the University of Leeds.

C. D. Green, A. P. Halestrap, D. I. A. MacLeod, J. R. Rhodes, Barbara M. F. Pearse, Elizabeth C. Cartwright and **C. R. Hiley** have been elected to Beit Memorial Junior Fellowships for Medical Research.

David Anthony King has been appointed to the Brunner Chair of Computer Studies at the University of Liverpool.

Geoffrey Bernard Cook has been appointed to the Chair of Computer Studies at the University of Hull.

D. P. J. Browning, Violet R. Cane, K. M. Clayton and **T. W. Goodwin** have been appointed to the University Grants Committee.

A. S. V. Burgen, J. N. Walton, S. Cohen and **D. C. Phillips** have been appointed to the Medical Research Council.

Awards

Denys H. Wilkinson has been awarded the American Physical Society's 1974 **Tom W. Bonner Prize** in Nuclear Physics.

The **Linnean Gold Medal** of the Linnean Society of London has been awarded to **E. H. W. Hennig** and **J. Braun-Blanquet**. The **H. H. Bloomer Award** has been presented to **A. F. Millidge**, and **George H. Locket**.

Corrigendum

In the article "Heavy ion transfer reactions in nuclear astrophysical processes" by T. W. Conlon (*Nature*, **247**, 268; 1974) the third paragraph from the end should read as follows. "A study of the α -transfer reaction $^{12}\text{C}(^{16}\text{O}, ^{20}\text{Ne})^{8}\text{Be}$ at energies in the region of the Coulomb barrier has been made possible by the development of a particle identification system based on position-sensitive counters mounted in the focal plane of a Bueschner spectrophotograph. Preliminary results indicate that significant amounts of ^{20}Ne are produced with respect to ^{24}Mg , which results from the principal compound nucleus channel (Table 2)."

In the same article, the following corrections should have been made; para. 1, line 12 should read "corresponds to the transfer of an α particle, . . ." para. 10, line 5, "available for later evolutionary . . ." and the last column in Table 1 should be " Q opitum (MeV) corresponding to (E min to E max)."

International meetings

July 8–10, **15th Annual Meeting of the Society for Economic Botany** (Mr Bruce Alderman, Kellogg Centre, MSU, S. Harrison Road, East Lansing, Michigan 48824).

July 23–24, **550th Meeting of the Biochemical Society** (The Meeting Officer, The Biochemical Society, 7 Warwick Court, Holborn, London WC1R 5DP).

August 5–9, **7th Semi-Annual Short Course on Laser Safety** (R. James Rockwell, Jr., Laser Safety Course, Conmed, 114 Medical College, Cincinnati, Ohio 45219).

August 26–28, **Pacific Slope Biochemical Conference** (Calvin S. McLaughlin, Secretary-Treasurer, Department of Molecular Biology and Biochemistry, University College Irvine, Irvine, California 92664).

Reports and Publications

Great Britain

Cancer Treatment Reviews, Vol. 1, No. 1, March 1974. Edited by K. Hellmann and S. K. Carter. Pp. 1–80. Subscription:— Vol. 1 (4 issues) March–December 1974, Inland £6.50 inclusive of postage; abroad £7.50 inclusive of postage. (London and New York: Academic Press, a Subsidiary of Harcourt Brace Jovanovich, Publishers, 1974.) [164]

The Annual Report of the Science Policy Research Unit at the University of Sussex for the year 1973. Pp. 54. (Brighton: SPRU, University of Sussex, 1974.) [164]

Medical Research Council. Memorandum No. 44: Haemophilia and its Related Conditions—a Brief Guide to Diagnosis and Treatment. By Rosemary Biggs. Pp. v + 42. (London: HMSO, 1974.) 34p net. [164]

Flora of Tropical East Africa. Edited by R. M. Polhill. Gramineae (Part 2). By W. D. Clayton, S. M. Phillip and S. A. Renvoize. Pp. 177–449. (London: Crown Agents for Oversea Governments and Administrations, 1974. Published on behalf of the East African Community.) £2.75. [164]

Unilever. Report and Accounts for 1973. Pp. 48. (London: Unilever, 1974.) [164]

Bulletin of the British Museum (Natural History). Zoology, Vol. 26, No. 3: Observations on *Trinema lineare* Penard (Testacea: Protozoa). By Ronald Henderson Hedley and Colin Gerald Ogden. Pp. 185–199 + 7 plates. (London: British Museum (Natural History), 1974.) £1.50. [184]

Process Engineering of Pyrometallurgy. (Proceedings of a joint meeting of the Institution of Mining and Metallurgy and the Institution of Chemical Engineers.) Edited by M. J. Jones. Pp. vi + 105. (London: The Institution of Mining and Metallurgy, 1974.) 26.50. [194]

The Way Ahead in Postgraduate Medical Education. Papers by Stanley Clayton, J. O. F. Davies, R. B. Hunter, Sir George Pickering, John Revans, Elizabeth Shore, George Smart, Sir Charles Stuart-Harris, Selwyn Taylor and G. I. Watson. Edited by Gordon McLachlan. Pp. 113. (London, New York and Toronto: Oxford University Press, 1974. Published for the Nuffield Provincial Hospitals Trust.) £1.25 net. [224]

Agricultural Administration, Vol. 1, No. 1, January 1974. Edited by A. N. Duckham and John Pearce. Pp. 1–88. Subscriptions: Four quarterly issues per volume (approximately 320 pages)—£10 (\$25, subject to exchange fluctuations.) London: Applied Science Publishers, Ltd., 1974. [224]

Parliamentary and Scientific Committee. Annual Report for 1973. Pp. 15. (London: Parliamentary and Scientific Committee, 1974.) [234]

Imperial Cancer Research Fund. Scientific Report to the Council by the Director of Research for the year 1973. Pp. 137. (London: Imperial Cancer Research Fund, 1974.) [234]

The Fourth Television Network: a Question of Priorities. By Sir Charles Curran. Pp. 18. (London: BBC, 1974.) [244]

Scientific Proceedings of the Royal Dublin Society. Series A. Vol. 5, No. 1: The Volcanic Rocks of the Carrigogunnell Area, Co. Limerick. By P. Strogen. Pp. 1–26 + plates 1–3. £1. Vol. 5, No. 2: The Structural Setting of the Leinster Granite, Ireland. By James C. Brindley. Pp. 27–36. Vol. 5, No. 3: Artificial Key for the Identification of the Fruits of Irish Grasses. By M. A. Farragher. Pp. 37–54 + plates 4–7. £1. Vol. 5, No. 4: Poaceae—Irish Members. Part IV: Classification. By M. A. Farragher. Pp. 55–76 + plate 8. £1. Vol. 5, No. 5: The Petrography of some Red-Feldspar Pegmatites and Their Association with Late Hydrothermal Changes in the Leinster Granite. By P. S. Kennan. Pp. 77–84 + plates 9 and 10. 70p. Series. Vol. 3, No. 16: Some Recent Researches on the Growing of Fibre Flax. By M. Neenan and J. Devereux. Pp. 201–220 + plate 11. 50p. (Dublin: Royal Dublin Society, 1973 and 1974.) [244]

The Zoological Society of London. Annual Report for 1973. Pp. 62. (London: The Zoological Society of London, 1974.) [254]

Essential Oils. Pp. 32. (London: Bush Boake Allen, Ltd., Blackhorse Lane, E17, 1974.) [254]

Bulletin of the British Museum (Natural History). Entomology, Vol. 30, No. 2: A Revision of Some Groups of *Liptena* Westwood (Lepidoptera: Lycaenidae). By H. Stempffer, N. H. Bennett and S. J. May. Pp. 107–181 + 6 plates. £4.75. Zoology, Supplement 6: The Cichlid Fishes of Lake Victoria, East Africa—The Biology and Evolution of a Species Flock. By P. H. Greenwood. Pp. 1–134 + 1 plate. £3.75. (London: British Museum (Natural History), 1974.) [264]

Fisons Limited. Report and Accounts for the year ended 31 December 1973. Pp. 31. (London: Fisons Limited, 1974.) [294]

British Museum (Natural History). Mineralogy Leaflet No. 5: Natural Crystals. Pp. 12. 9p. Simple Crystal Models, Sheets 1 and 2. (London: British Museum (Natural History), 1974.) [304]

Journal of Archaeological Science, Vol. 1, No. 1, March 1974. Edited by G. W. Dimbleby, D. R. Brothwell and H. Barker. Pp. 1–116. Subscription: 1974, Vol. 1, 4 issues, Inland £8 including postage; abroad £9.10 including postage. (London and New York: Academic Press, 1974.) [15]

Other Countries

Physics Reports of the Kumamoto University, Vol. 1, No. 1, 1973. Pp. 1–72. (Kumamoto: Department of Physics, Kumamoto University, 1973.) [164]

Marine Aquariums in the Research Laboratory. By John M. King and Stephen Spottle. Pp. 40. (Eastlake, Ohio: Aquarium Systems, Inc., 33208 Lakeland Blvd., 1974.) \$2. [164]

Alberta Research—Annual Report for 1973. Pp. 65. (Edmonton, Alberta: Research Council of Alberta, 1974.) [164]

Canada: Department of Energy, Mines and Resources. Geological Survey of Canada, Paper 72–20: Stratigraphy of the Southern Part of the Devonian Ancient Wall Carbonate Complex, Jasper National Park, Alberta. By E. W. Mountjoy and W. S. Mackenzie. Pp. vii + 121 (8 plates). \$3. Paper 73–9: Reconnaissance Studies of Proterozoic and Cambrian Stratigraphy, Lower Mackenzie River Area (Operation Norman), District of Mackenzie. By J. D. Aitken, R. W. Macqueen and J. L. Usher. Pp. vii + 178 (22 plates). \$4.50. Paper 73–33: Deltaic Sedimentation in the Northeastern Bowser Basin, British Columbia. By G. H. Eishbacher. Pp. 13, \$2. (Ottawa: Information Canada, 1973 and 1974.) [174]

Smithsonian Contributions to Zoology, No. 127: A Revision of the Family Lichomolgidae Kossman, 1877. Cyclopoid Copepods Mainly Associated with Marine Invertebrates. By Arthur G. Humes and Jan H. Stock. Pp. v + 368. (Washington, DC: Smithsonian Institution Press, 1973. For sale by US Government Printing Office.) \$4.50. [174]

Volume One of the Report and Recommendations of the National Advisory Commission on Multiple Sclerosis—an Overview. Pp. i + 67. (Bethesda, Md.: US Department of Health, Education and Welfare, Public Health Service, National Institute of Health, 1974.) [184]

Republic of South Africa: Department of Industries. Sea Fisheries Branch Investigational Reports. No. 106: Growth of Juvenile Rock Lobster *Jasus lalandii*. By D. E. Pollock. Pp. 16. No. 108: Oceanic Circulation Deduced from Plastic Drift Cards. By L. V. Shannon, H. G. Stander and J. A. Campbell. Pp. 31. (Sea Point, Cape Town: Sea Fisheries Branch, 1973.) [184]

Science Council of Canada. Background Study No. 30: A Technology Assessment System—a Case Study of East Coast Offshore Petroleum Exploration. By M. Gibbons and R. Voyer. Pp. 114. (Ottawa: Information Canada, 1974.) [184]

Energy, Mines and Resources Canada—Annual Report 1972/1973. Pp. 33. (Ottawa: Information Canada, 1974.) [184]

New Zealand: Board of Health. Report Series No. 18: Drug Dependency and Drug Abuse in New Zealand—Second Report. Pp. 247. (Wellington: Government Printer, 1973.) [194]

New Zealand: National Radiation Laboratory. Environmental Radioactivity: Fallout from Nuclear Weapons Tests Conducted by France in the South Pacific During July and August 1973, and Comparisons with Previous Test Series. Pp. 29. (Christchurch, NZ: National Radiation Laboratory, 1973.) [194]

Smithsonian Contributions to Zoology, No. 155: The Familial Phylogeny of the Tetraodontiformes (Acanthopterygii: Pisces) as Evidenced by Their Comparative Myology. By Richard Wootton. Pp. iv + 199, \$2.80. No. 157: A Bibliography of the Catalogs, Lists, Faunal and Other Papers on the Butterflies of North America, North of Mexico. Arranged by State and Province (Lepidoptera: Rhopalocera). By William D. Field, Cyril Dos Passos and John H. Masters. Pp. 104. \$1.70. No. 160: Systematics of the Subterranean Amphipod Genus *Stygobromus* (Gammaridae), Part I: Species of the Western United States. By John R. Holsinger. Pp. iii + 63. \$1.45. (Washington, DC: Smithsonian Institution Press, 1974. For sale by US Government Printing Office.) [224]

Institut Royal Météorologique de Belgique. Publications. Série A, No. 83: Représentations Analytiques des Composantes du Rayonnement Lumineux Solaire: Conditions de Ciel Seren. Par R. Doniaux. Pp. 24. Série A, No. 85: L'Évapotranspiration Potentielle des Bassins Hydrographiques en Belgique. Par Franz Bulot et G. L. Dupriez. Pp. 61. Série B, No. 75: Some Remarks About the Temperature Effect on Meson Telescope Data. By Dr. A. Van Gysegem. Pp. 11. (Bruxelles: Institut Royal Météorologique de Belgique, 1974.) [234]

Canada: Department of Energy, Mines and Resources. Geological Survey of Canada, Paper 73–2: Age Determinations and Geological Studies, K–Ar Isotopic Ages, Report 11. By R. K. Wanless, R. D. Stevens, G. R. Lachance and R. N. Delabio. Pp. 139, \$3. Paper 73–7: Geological Survey of Canada—Radio carbon Dates XIII. By J. A. Lowdon and W. Blake, Jr. Pp. vii + 61. \$2. Paper 74–18: Sulphur in Archean Volcanic Rocks of the Canadian Shield. By F. M. Cameron. Pp. 9, \$2. Paper 74–19: Analysis of Rocks and Minerals Using an Atomic Absorption Spectrophotometer. Part 5: An Improves Lithium-Fluoroborate Scheme for Fouteen Elements. By S. Abbey, N. J. Lee and J. L. Bouvier. Pp. iv + 26. \$2. (Ottawa: Information Canada, 1973 and 1974.) [254]